



Planetary Science Technology Infusion Study Findings and Recommendations Status

*David J. Anderson, Carl E. Sandifer II, Timothy R. Sarver-Verhey, Daniel M. Vento, and June F. Zakrajsek
Glenn Research Center, Cleveland, Ohio*

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National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

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Planetary Science Technology Infusion Study

Findings and Recommendations Status

David J. Anderson, Carl E. Sandifer II, Timothy R. Sarver-Verhey,
Daniel M. Vento, and June F. Zakrajsek
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Technology infusion means the pathway by which technologies, previously unused by space flight programs, move from their current status onto space flight missions. The technology can be several generations old, the state-of-the-art or anything that is deemed useful to the accomplishment of NASA space missions. (Ref. 1)

Introduction

The Planetary Science Division (PSD) within the National Aeronautics and Space Administration's (NASA) Science Mission Directorate (SMD) at NASA Headquarters sought to understand how to better realize a scientific return on spacecraft system technology investments currently being funded. In order to achieve this objective, a team at NASA Glenn Research Center was tasked with surveying the science and mission communities to collect their insight on technology infusion and additionally sought inputs from industry, universities, and other organizations involved with proposing for future PSD missions. This survey was undertaken by issuing a Request for Information (RFI) activity that requested input from the proposing community on present technology infusion efforts. The Technology Infusion Study was initiated in March 2013 with the release of the RFI request. The evaluation team compiled and assessed this input in order to provide PSD with recommendations on how to effectively infuse new spacecraft systems technologies that it develops into future competed missions enabling increased scientific discoveries, lower mission cost, or both. This team is comprised of personnel from the Radioisotope Power Systems (RPS) Program and the In-Space Propulsion Technology (ISPT) Program staff.

The RFI survey covered two aspects of technology infusion: 1) General Insight, including: their assessment of barriers to technology infusion as related to infusion approach; technology readiness; information and documentation products; communication; integration considerations; interaction with technology development areas; cost-capped mission areas; risk considerations; system level impacts and implementation; and mission pull. 2) Specific technologies from the most recent PSD Announcements of Opportunities (AOs): The Advanced Stirling Radioisotope Generator (ASRG), aerocapture and aeroshell hardware technologies, the NASA Evolutionary Xenon Thruster (NEXT) ion propulsion system, and the Advanced Materials Bi-propellant Rocket (AMBR) engine.

This report will present the team's Findings from the RFI inputs and the recommendations that arose from these findings. Methodologies on the findings and recommendations development are discussed.

Motivation for Conducting PSD Technology Infusion Study

Planetary Science Division has a long history of technology investment that is not limited to science instrumentation. There is considerable investment in spacecraft technologies that will extend and enhance the science return of future missions. These technologies for solar system exploration were identified in the 2006 Solar System Exploration Roadmap (Ref. 2) and subsequently thoroughly assessed and presented in the last Decadal Survey (Ref. 3), with several recommendations for targeted technology advancement. These technologies have shown to have enabling or critical applicability across a broad range of the missions of interest to PSD. The organization responded with substantial technology

TABLE 1.—TECHNOLOGY INFUSION SUMMARY

PSD Program, AO year	Incentive amount, \$M	Incentivized technology	Community response	Outcome (number selected)
New Frontiers 3, 2009	15	NEXT thruster and PPU	Two proposals used NEXT	None accepted
	5	AMBR thruster	No Proposals	None accepted
Discovery 12, 2010	GFE	ASRG	Six Step 1 proposals	Two Step 2 proposals. Non-ASRG mission
	19	NEXT thruster and PPU	Three proposals used NEXT	None accepted
	10 20	Aerocapture TPS and hot structures, or Aerocapture Maneuver	Two proposals used Aerocapture TPS/HS	None accepted
	5	Use of AMBR thruster	No proposals	—

investment and incentive approaches designed to encourage Mission Planners, Principal Investigators, and Space Scientists to take advantage of these technologies. NASA's New Millennium Program was a productive avenue to technology validation through targeted flight opportunities until its conclusion in 2007. Subsequent technology infusion programs were integral elements of the most recent proposal activities in 2009 (New Frontiers 3) (Ref. 4) and 2010 (Discovery 12) (Ref. 5) where they were identified for broad applicability of missions of interest. The description of these activities, as well as more detail on the Decadal Survey results, is presented in Appendix C.

Even though PSD has been investing in the development of relevant and enabling technologies for over 13 years, the technology incentivization in the last Discovery and New Frontiers AO's has not led to the adoption of any of these technologies in a funded mission. A summary of the technology infusion for the two AO's is summarized in Table 1.

The Decadal Survey said that these technologies continue to be of high value to a wide variety of solar system missions and that NASA should continue to provide incentives for these technologies until they are demonstrated in flight. At the present stage, the organization was concerned about the effectiveness of its investments. The technology development programs and PSD management are motivated to understand how to better realize a scientific return on spacecraft system technology investment.

Technology Infusion Study

Study Charter and Team

The Planetary Science Division (PSD) chartered this study to understand how to better realize a scientific return on spacecraft system technology investment by enabling the first use of these technologies through competed mission opportunities. To this end, PSD formed a team comprised from the Radioisotope Power Systems Program and the In Space Propulsion Technology Program staff to execute this study. These two Programs within PSD are focused on developing technology to support planetary mission needs. The full charter is provided in Appendix A for reference.

The primary objective of this study was to provide PSD with recommendations on how to effectively infuse new spacecraft systems technologies into future competed missions enabling increased scientific discoveries, lower mission cost, or both. In order to answer this objective, the questions in Table 2 were used to develop a Request for Information (RFI) that solicited the community's input.

TABLE 2.—FORMULATING QUESTIONS FOR THE RFI

Questions
How can technology efforts be better developed, communicated, and offered to allow for implementation into a competitively selected mission?
How mature does a new technology need to be before being recognized as viable and ready for infusion by the end user?
What are the barriers to the use of newly developed technologies in competed missions?
What were the benefits and limitations of the technology incentive methodology used in the New Frontiers 3 and Discovery 12 AO's?
How can the technology incentive methodology be improved?
How did the DSMCE study impact the evaluation of the ASRG technology in mission concept planning and the development of a proposal in response to the Discovery 12 AO?
How does PSD reduce real and perceived new spacecraft system impact on mission risk?
From the end user perspective, are there any other viable options for technology infusion which NASA could consider?

There are two secondary objectives that were considered, 1) For the RPS Program, understand Discovery 12 (Ref. 5) lessons learned from proposers and evaluators regarding the integration of the ASRG into mission concepts; and 2) For the In-Space Propulsion Program, understand lessons learned from proposers and evaluators regarding the use of NEXT, Aerocapture, and AMBR for Discovery/New Frontiers (Refs. 4 and 5) class missions. Additionally, what were some specific reasons that these incentivized technologies were not proposed in response to the recent Discovery/New Frontiers AO's? (Refs. 4 and 5)

Study Approach and RFI Responses Received

The approach taken to answer these questions and fulfill the study charter comprised releasing an RFI, analyzing the data acquired, a series of discussion with the community and responders, an update if required, documentation of the study and final presentations and dissemination of the results. An RFI was used to maximize our contact with the members of the science and mission communities. The RFI had three sets of questions that were provided in appendixes. RFI Appendix A asked questions that were relevant to any science technology area, where RFI Appendix B and C asked questions specific to the In-Space Technology Program and the Radioisotope Power Systems Technology Program, respectively. The RFI is provided in Appendix B. The RFI requested specific responses to questions that were derived based on the questions in Table 2 as well as an open response to submit other consideration that the questions might not have covered.

The RFI generated 11 responses from within Industry and the government that represented a good cross-section of the user community. Table 3 provides a list of the responders and the sections of the RFI to which they provided responses. The responders were able to respond to sections that were applicable to their experience and interests. Two of the responders, TASC and Charles Stark Draper Lab, did not directly respond to the questions in the appendix but did provide approaches for assessing technology readiness and utility for PSD.

During the analysis phase the study team generated common themes across the input received, and developed recommendations based on these themes. This process is explained in detail in the next section.

This report captures the findings based on the RFI submissions and the derived recommendations that will be delivered to PSD in order to inform and support an upcoming Announcement of Opportunity. Further information will be gathered from the user community during dissemination of the report at future conferences and Analysis and Assessment Group meetings. Any new insights of significant merit will subsequently be brought forward to PSD. The Technology Infusion Study is synergistic with several other related study activities, as shown in Figure 1.

TABLE 3.—RFI RESPONDERS BY ORGANIZATION, ENTITY, APPENDIX IDENTIFIED TO WHICH THEY RESPONDED AND THE NUMBER OF PAGES OF THEIR INPUT

Organization	Entity type	App. A	App. B	App. B (2)	App. C
Aerojet (25 pages)	Corporate	✓	✓	✓	
Ball Aerospace (11 pages)	Corporate	✓	✓	✓	✓
The Boeing Company (13 pages)	Corporate	✓	✓	✓	
Lockheed-Martin (8 pages)	Corporate	✓	✓		✓
John Hopkins University, APL (20 pages)	Federal Lab	✓	✓	✓	✓
NASA Jet Propulsion Laboratory (45 pages)	Federal Lab	✓	✓	✓	✓
NASA Ames Research Center (4 pages)	Government		✓		
NASA Marshall Space Flight Center (13 pages)	Government	✓	✓		✓
NASA Goddard Space Flight Center (18 pages)	Government		✓		
TASC (27 pages)	Corporate	*			
Charles Stark Draper Lab (6 pages)	Federal Lab	*			

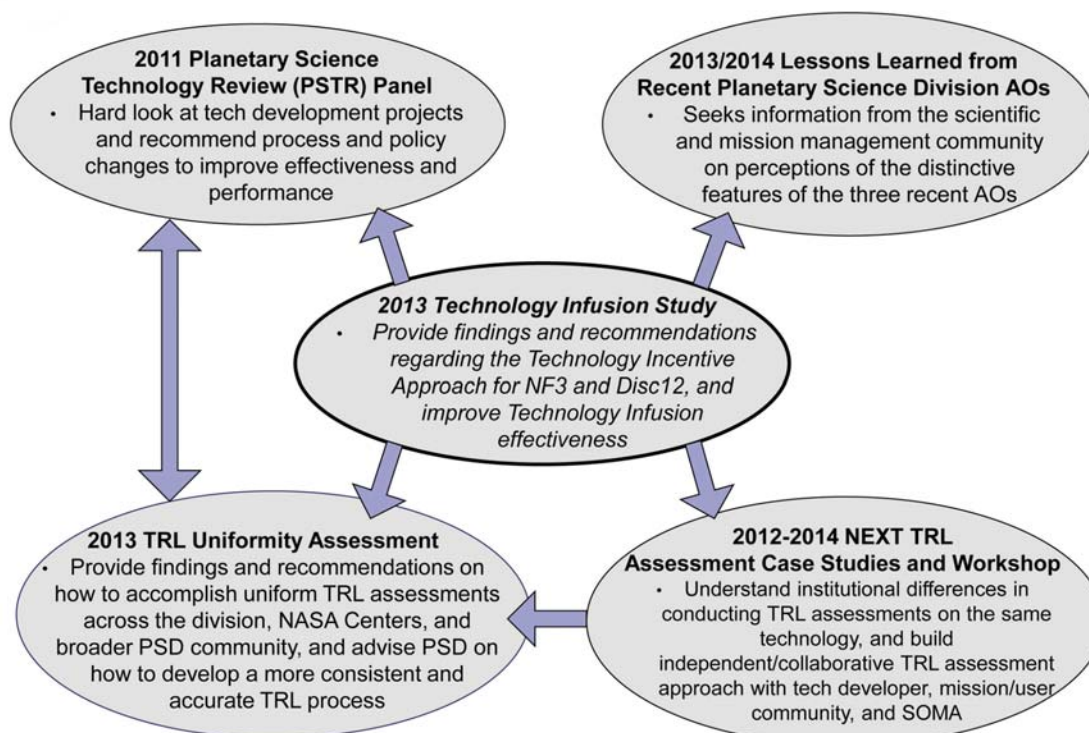


Figure 1.—The Technology Infusion Study will feed other related studies

Analysis Approach

Steps

Request for Information (RFI) submissions from 11 respondents were reviewed by the evaluation team. As mentioned previously, the RFI was divided into three domains. These were:

- General insights on technology infusion by PSD and NASA (RFI Appendix A)
- Targeted insights on the technologies under development by the In-Space Propulsion Technology (ISPT) program (RFI Appendix B)
- Insights on the agency's RPS/ASRG infusion efforts (RFI Appendix C)

The respondents were provided a set of questions for each of these domains. These questions were typically open, and did not provide instruction or limit the types of responses that could be provided. Hence, there was significant overlap and diversity of responses. Consequently, this made it difficult to use the question structure to organize the responses in an effective fashion.

While in hindsight it should have been foreseen, the responses in many cases focused on a portion of the technology areas discussed in the RFI. Consequently, the team found that, while there were significant inputs for several topics, there were very limited inputs for other questions.

The evaluation team collected the responses into a set of findings that captured what the team identified as the important messages conveyed by the respondents.

The initial set of findings was determined upon reading all of the submissions and extracting critical and substantive statements that provided insight and information. These statements were organized into specific topics. From the set of collected statements, the evaluation team developed the “Findings” statement text. The Findings statements were structured to represent a specific declaration of the current state of an identified situation. The supporting text quotes from the RFI documents were then used to establish a scoring based on the degree of support for or against the Findings statement. These scores identified how much the statement is perceived as correct or incorrect by the respondents. The Findings statements, support statements, and scoring were reviewed extensively by the evaluation team. The organization of the Findings evolved through these discussions before arriving at the current four category structure. The final findings set are represented in the tables in the Appendix D. Figure 2 pictorially shows the study analysis method.

The process for capturing and consolidating the findings can be summarized in the following steps:

- Extracted 545 relevant responses from 190 pages
- Grouped similar extracted responses and developed 71 short finding statements
- Consolidated statements into the four common themes from the Planetary Science Technology Panel’s (PSTRP) Issues and Recommendations (Ref. 6)
 - Strategic, Process/Structure, Resource, and Culture/Communication
- Determined level of respondent agreement within the finding statement (see Appendix D)

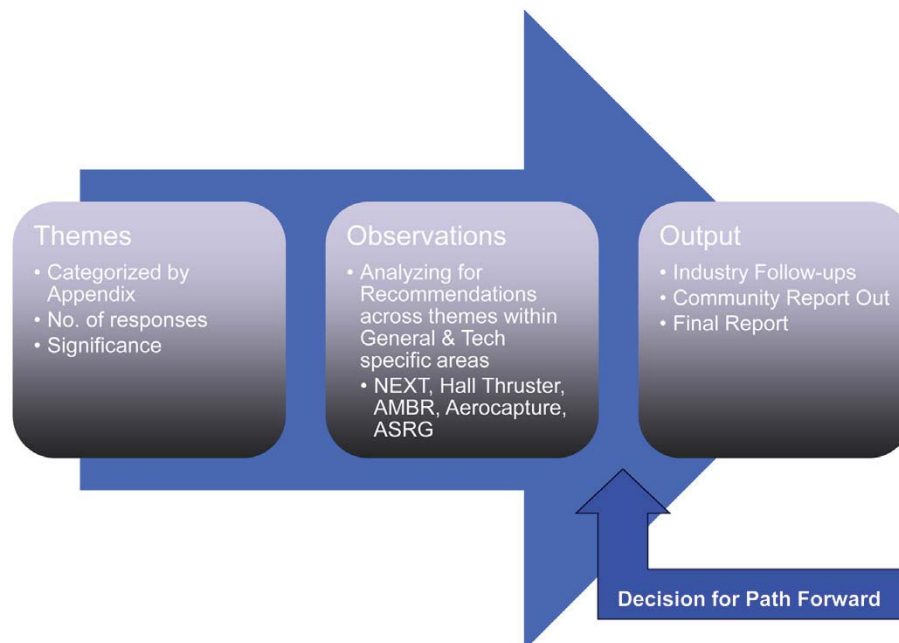


Figure 2.—Study analysis method

The process for capturing and consolidating the recommendations can be summarized in the following steps:

- Created 11 consolidated respondent-based recommendations from 113 explicit and implicit recommendations in the RFI responses
- Developed 12 team based recommendations after analyzing the RFI responses, and considering additional knowledge and insights from meetings, studies, and outside discussions with the planetary community and HQ
- Consolidated into 14 Recommendations, and grouped under the four Themes (see Appendix E)
 - Used the same “Themes” as used in the Planetary Science Technology Panel’s (PSTRP) Issues and Recommendations (Ref. 6)

Findings and Recommendations

Executive Summary of the Findings

The findings from the Technology Infusion Study indicate that the End-User Community (Industry/proposers) want to use NASA developed technologies to support PSD missions (Decadal finding and recommendation). The technologies enable or are applicable to 36 of 47 missions identified in the Decadal Survey. However, these enabling technologies are either perceived not to be ready or are not actually ready for infusion into missions. The results of the study indicate that there is a need to resolve technology readiness issues, to complete development, to document better, and to qualify the technologies for infusion. This last finding is also a Decadal Survey Recommendation.

At the present, proposers perceive SOMA to judge new technologies as high risk, which prevents their use in proposals and possible infusion. Current incentives for technologies are not sufficient to overcome real or perceived risks, and implementation and/or accommodation costs that will limit Return on Investment (ROI). This results in PSD losing credibility when it comes to technology development and infusion. Examples of this are stopping the flight hardware development of the ASRG and not selecting mission proposals with incentivized technologies. While the Planetary Decadal Survey supports the continued development and incentivization of these PSD developed technologies, these actions introduce uncertainty in the community on how PSD might support or incentivize technologies in the future.

The Technology Infusion Study findings and recommendations are consistent and synergistic with the Planetary Decadal Survey (Ref. 3) the Planetary Science Technology Review Panel (PSTRP) (Ref. 6), and the TRL Uniformity study findings and recommendations (Ref. 7).

As previously mentioned within the Study Charter and Team section, the Technology Infusion Study RFI had three sets of questions that were provided in appendixes. RFI-Appendix A asked questions that were relevant to any science technology area, where RFI Appendix B and C asked questions specific to the In-Space Technology Program and the Radioisotope Power Systems Program, respectively. The full text of the RFI is provided in Appendix B of this document. The RFI requested specific responses to questions that were derived based on the questions in Table 2 as well as an open response to submit other consideration that the questions might not have covered. Throughout the remainder of the document, the term “infusion technologies” will generally be used to refer to the set of Advanced Stirling Radioisotope Generator (ASRG), aerocapture maneuver and aeroshell hardware, the NASA Evolutionary Xenon Thruster (NEXT) ion propulsion system, and the Advanced Materials Bi-propellant Rocket (AMBR) engine technologies which PSD has been developing and is trying to infuse into future missions.

Summary of the General Findings (RFI Appendix A Questions)

After collecting and collating the data, the evaluation team grouped the findings within the following four themes:

1. **Strategic:** “How technology enables science for PSD”
- 2a. **Process/Structure: AO Implementation—**“How best to infuse technology into missions”
- 2b. **Process/Structure: Technology and Implementation—**“How to ensure technologies are infusion ready”
3. **Resources:** “How can resource availability and utilization improve technology development and infusion?”
4. **Culture/Communications:** “How can culture and communication be improved to support technology development and infusion?”

The findings associated with each of these themes can be found below. The complete list of findings with the level of respondent agreement can be found in Appendix D.

Strategic

The RFI respondents expressed that NASA is supporting the right infusion technologies, which are more attractive because they are mission enabling, and are needed to further planetary science missions. They also recommended that NASA continue to develop the infusion technologies.

Process/Structure—AO Implementation

In order to infuse technologies into missions, the respondents expressed that mission opportunities for the infusion technologies should be mandated. They also noted that Capability Enhancement studies are beneficial to technology infusion efforts. (Reference information on the 2007 Discovery and Scout Mission Capabilities Expansion (DSMCE) study can be found in Appendix C.)

In addition, they expressed that incentives provided by NASA to date were insufficient to enable higher value missions by offsetting risk and completing maturation and implementation. However, providing government furnished equipment (GFE) is a preferred incentive because the government assumes the risk.

With respect to the AO process, the respondents felt that the requirements for proposal submission were not fully communicated and that there was limited transparency in the selection process and criteria. Another general finding is that the process of the Technical, Cost, Management, and Other Factors (TMCO) panel used to evaluate major flight mission projects is perceived as risk-averse and resistant to new technologies. There is also a belief that the panel may lack the sufficient information necessary to adequately make assessments of the infusion technologies.

Process/Structure—Technology Development

The respondents expressed opinions about the process associated with technology development. They emphasized that there is a lack of consensus on the status of Technology Readiness Levels and their meaning. Currently, TRL determination depends upon the evaluator (technologist, mission designer, user, SOMA) with different backgrounds and perception of TRLs. The responders noted that there are numerous instances where inconsistent TRL designations from heritage technologies are claimed. TRL should be established at the system level, and not targeted components. In many cases, the infusion technologies are not demonstrated at target conditions (relevant environments). Technology development precedes knowing the relevant environments of selected missions, which adds complexity to the technology development and TRL determination.

In addition, TRL designation should be determined by an independent party and separate from the technology developer. From an AO process standpoint, TRL designation is typically not validated in time to support AO release and proposal development. TRL status is time dependent and requires maintenance. As a result, in many cases, technology becomes unviable due to limited use, leading to loss of capability.

Resources

The responders noted that accommodation costs are not being addressed with the incentives provided by NASA. These accommodation costs include implementation, launch vehicle and safety, and integration. Adequate resources have to be provided to ensure that technology development can accommodate mission pull. Technology development should be coordinated with the Science Technology Mission Directorate (STMD) and others.

Culture/Communications

With regards to addressing the impact of communication to improving technology development and infusion, the respondents re-iterated that TRL designation and supporting information data/documentation was insufficient. This information needs to be established prior to AO release and infusion technology documentation needs to be fully matured to meet the user needs for spacecraft integration. The community expressed that TMCO does not have sufficient information to evaluate technology risk, which is necessary to ensure a level playing field for proposers. The proposers would like more Subject Matter Expert (SME) access throughout the proposal process. They noted that direct communication with the experts is critical to resolving risk and ensuring successful mission development.

After consolidating the general findings that were applicable throughout the study, the evaluation team captured infusion technology specific findings and they are found below.

Summary of Specific ISPT Findings (RFI Appendix B Questions)

NEXT Ion Propulsion System

- The mission and science community wants the NEXT system. However, the thruster is at TRL 6 but the system as a whole is not. Completion of the Power Processing Unit (PPU) is necessary.
- Electric Propulsion (EP) accommodation requires increased spacecraft power
- Incentives for infusion are insufficient, though utilizing GFE could be viable.

Hall Effect Thruster Propulsion (HET) for PSD Missions

- PSD Hall system wanted by the science and mission community. Thruster options are currently in development but a mature PPU is needed to meet planetary requirements.
- EP accommodation requires increased spacecraft power
- Cost-sharing incentive viability mixed throughout the community. Utilizing GFE could be viable.
- The HET system is more attractive when there are multiple use applications

AMBR Chemical Thruster

- Not ready, interest mixed, incentives/GFE not viable.
- Two Divergent views: Some responders expressed that the current AMBR 140 lb thruster needs to be at TRL 8. Others conveyed that significant changes to the AMBR thruster capabilities are needed (to achieve original goals).

Aerocapture

- Aerocapture maneuver technology is critical for flagship missions beyond current decadal priorities. Use of new thermal protection system (TPS) materials would be beneficial over heritage implementation
- Two Divergent views on flight readiness exist: Some expressed that flight demonstration is needed. Others communicated that the technology is ready and no further development is required.
- Little interest in cost-sharing incentives
- Aerocapture infusion was limited by institutional/organizational constraints. (Example: One vendor who developed an Aerocapture technology was reluctant about supporting a competing proposal using that technology while it was pursuing its own proposals for that AO.)

Summary of ASRG Findings (RFI Appendix C Questions)

Advanced Stirling Radioisotope Generator (ASRG)

- Incentives were considered disincentives by some members of the community
- Implementation costs that were not covered burdened proposers
- Parallel technology development with proposal development created issues
- There was an inability to share content with mission proposers during proposal process
- Technical implementation issues kept slipping
- Perception by the proposers that SOMA believed ASRG was risky
- Lack of consensus on TRL status
- Program Library (documentation) needs improvement
- Direct communication provided was valuable, and should be expanded
- Infusion was hindered by complex organizational relationships between NASA and the Department of Energy

Cross-Cutting Technology Finding

- The infusion technologies need additional maturation to achieve TRL 6 as a system and are not currently ready for integration.

PSD Technology Infusion Recommendations

The consolidated set of 14 recommendations to improve PSD technology infusion efforts can be found below. Prospective implementation approaches can be found within the sub-bullets. The majority of the recommendations were derived directly from the findings, and the mapping of their dependencies can be found within Appendix D and Appendix E at the end of this report. The term “infusion technologies” continues to refer to (ASRG, NEXT, etc.), while the term “technologies considered for infusion” will be used generically, but could also include the current “infusion technologies.”

I. Strategic: Technology Investment Portfolio

1. Provide resources to enable successful technology infusion and being a “smart buyer” for PSD unique/critical mission needs

II. Process/Structure: Technology Development and Implementation: TRL

2. Implement a defined, transparent, and independent process for validating and documenting that a technology being considered for infusion has achieved TRL 6 (or more), 9 months (or more) prior to AO release

- a. A technology to be considered for infusion should be at a system-level TRL 6 nominally 6 to 18 months prior to AO release.
- b. Improve and maintain documentation for technologies being considered for infusion to ensure necessary information is available to interested parties
- c. Establish independent body to conduct TRL determination
- 3. Complete development and qualification of the current infusion technologies (ASRG, NEXT, etc.) to alleviate risks and meet the needs of future PSD missions
 - a. Finish technologies with a flight demonstration by any means to establish flight heritage
 - (1) Mandate the infusion technologies on an AO, provide funds for ride shares, re-establish New Millennium for NASA developed technologies, or negotiate TDM opportunities
 - b. Qualify to a set of Decadal Survey DRM's and/or generic requirements from mission user needs derived by holding a User Community TIM and/or vet through a Technology Advisory Panel

II. Process/Structure: Technology Development and Implementation

- 4. Determine accommodation costs/burdens associated with new technology adoption into future missions
- 5. Establish approach to sustain technology capability so that future PSD mission needs can be met
 - a. Develop PSD unique requirements to meet mission needs, and identify if technology needs are PSD unique
 - b. Evaluate use or modification of commercial products to meet PSD unique mission requirements
 - c. Develop PSD unique technologies with industry (transferring the technology out of PSD) to open the possibility of commercial flight opportunities
 - d. Commercialization/"Multiple-use" should be considered at the beginning of technology development for risk reduction and establishing flight heritage
- 6. The use of mission capability enhancement studies should be expanded to improve both the understanding of mission requirements and the constraints associated with implementing new technologies

II. Process/Structure: AO Strategies for Tech Infusion

- 7. PSD should present the incentive approach for the use of technologies considered for infusion approximately 9 to 12 months prior to AO release to establish common understanding for SOMA, industry and mission implementers, and technology developers
 - a. Documentation validating TRL 6 for any technology considered for infusion should be released no later than six months prior to AO release
 - b. Incentive approaches should address maturation of the technology from TRL 6 to flight implementation
- 8. PSD through the AOs should establish/designate missions that mandate the use of infusion technologies
 - a. Determine the science missions that would benefit significantly from infusion technologies (See II.3.b)
- 9. Incentives approach for technologies considered for infusion must address the completion of system-level development work (from TRL 6 to flight infusion) and address accommodation costs/impacts
 - a. Any technology being considered for incentivization must have an assessment of readiness and associated risk.
 - b. Qualify a new technology to DRM requirements, then re-qualify or delta qualify as necessary to Mission specific requirements when known

- c. Evaluate accommodation of technologies considered for infusion to mitigate barriers in the AO incentive approach (cost, risk, knowledge, etc.)
- d. To achieve more Decadal Survey science goals, PSD should increase the risk and cost that it is willing to accept regarding the use of technologies considered for infusion in future mission AO's
- e. PSD should determine its threshold regarding GFE versus cost sharing incentive limits for each infusion technology (including accommodation costs/impacts)
- f. The user community wants PSD to provide technologies as GFE and cover accommodation costs/impacts thru ATLO and Ops

III. Resources

- 10. Imperative that PSD complete technology development of the infusion technologies (ASRG, NEXT, etc.) to guarantee adoption into missions.
 - a. Provide sufficient and sustained resources to mature new/infusion technologies to TRL 6 by AO release
 - b. To ensure satisfactory development of infusion technologies, shorter development timescales will improve infusion with mission opportunities
- 11. Technology Portfolio Investment
 - a. Establish dedicated PSD spacecraft component technology program to assist future infusion activities, and provide sufficient resources to sustain PSD unique technical expertise/knowledge and facilities in NASA, industry, and academia
 - (1) Successful technology infusion must be sustained in a competitive environment

IV. Culture/Communication

- 12. Improve and ensure robust communication opportunities between technology developer, mission manager, and proposing communities to encourage better understanding of technologies considered for infusion
 - a. Ensure a representative POC or subject matter expert is available with authority to communicate and advise interested parties to ensure technologies considered for infusion are used properly to maximal benefit
 - b. NASA should ensure that all interested parties have fair and equitable access to the technologies considered for infusion
- 13. Establish a customer advisory board to advise PSD on technology needs, performance requirements, and evaluation approaches to ensure level playing field for all parties
 - a. Institute evaluation processes to avoid placing barriers to infusion of new technologies in the AO process
- 14. Develop partnerships with other organizations to broaden interest, appeal, and create sustaining support for technologies considered for infusion
 - a. Establish agreements to maximize cost sharing opportunities within the Agency (SMD, STMD, HEOMD)
 - b. Foster and maintain partnerships for advocacy between technology developers and users

Additional Technology Needs

The RFI asked for feedback on what other spacecraft bus technologies would be of the most interest to the planetary science mission community? The responses are summarized in Table 4, and are compared to those identified in the 2011 Planetary Decadal Survey (Ref. 3).

TABLE 4.—RFI RESPONSE SUMMARY AND DECADAL SURVEY COMPARISON

RFI New Technology Needs	Decadal Survey Technology Needs
Advanced Power and Propulsion	Propulsion: Electric and chemical propulsion
Green propellants	
Photovoltaic Arrays	Power: Photovoltaics and RPS
– Increased Efficiency cell performance	
– Lower mass and stowability	
– Extended extreme environment capabilities – (Low-intensity, low-temperature; high-temperature, high-intensity; higher radiation tolerance)	
Thermal Protection systems – Carbon phenolic-like capabilities	Entry Vehicles Aerocapture/probes/EDL/EEVs/TPS
Deep Space Optical Communication	High data-rate communications
High bandwidth communications	
Reconfigurable avionics systems	
Low mass structures	Cross-cutting technologies seeking to reduce mass and power requirements
Ultra-lightweight Propellant Tanks	
Interplanetary Nano-Spacecraft	
Deep Space Atomic Clock	Autonomous operations
Sample Return/Handling Technologies	Extreme environments
Planetary Simulant Development	Mobility systems/platforms
	Mars/planetary ascent vehicles
	Mission design tools

Other Considerations

The incentivized “Infusion Technologies” considered in the RFI represented a diverse set of technology infusion approaches/challenges/considerations.

- ASRG as GFE
- NEXT as a propulsion system, not just a single component
- AMBR chemical thruster as a potential drop-in replacement
- Aerocapture is not just a component or a subsystem, it involves more system design and integration

The Technology Infusion Team noticed other competing technology development considerations which influenced the study responses or recommendations.

- Competed missions vs. Directed/other Government missions vs. Commercial applications
 - Multi-mission vs. Mission specific requirements
- Long timescale for technology development vs. Mission pull/priorities evolve over time which changes technology needs
 - Far-term vs. near-term mission needs for new technology
- Unique Planetary mission requirements vs. commercial flight hardware
 - Degree to which unique requirements are met vs. cost, risk, developing, and/or maintaining a unique technology

- New technologies provide increased spacecraft/mission capabilities
 - Enables more science value
 - Could increase mission complexity with higher cost and risk uncertainty, which are often at odds in a risk adverse cost constrained environment.

On February 20, 2014, the Science Mission Directorate (SMD) released a notice that it was planning on releasing a Draft Announcement of Opportunity (AO) for Discovery Program missions by May 2014. The community announcement discussed the following as it relates to technology infusion and addressing accommodation costs of implementing new technology capabilities:

- Discovery Program investigations may propose Technology Demonstration Opportunities (TDOs) to demonstrate new capabilities. TDO proposals... are funded outside of the cost cap and may possibly not be selected even if the parent mission is selected for flight.
- Discovery Program investigations involving entry, descent, and landing (EDL) into the atmosphere of a Solar System object (including the Earth) *shall* include an Engineering Science Activity, to be funded outside of the cost cap, to obtain diagnostic and technical data about vehicle performance and entry environments. Details of the goals and objectives of this activity will be posted on the Discovery Program Acquisition Website (discovery.larc.nasa.gov) in the Program Library.
- The schedule for fueling of radioisotope power systems (RPSs) cannot be met in time for the expected launch window of Discovery 2014 investigations. Therefore, Discovery Program investigations *may not* propose the use of RPSs.
- NASA is considering providing additional technologies as Government-Furnished Equipment (GFE). Currently under consideration is a commercially produced version of the NASA Evolutionary Xenon Thruster (NEXT) ion propulsion system (two flight model power processing units and two thrusters). Also under consideration is the Heat Shield for Extreme Entry Environment Technology (HEEET)—a woven Thermal Protection System.
- Decisions on the three technologies described above, or any other technologies (e.g., Deep Space Atomic Clock, Advanced Solar Arrays), will be made before the release of a draft AO.
- Launch Vehicle costs and procurement will be the responsibility of NASA. Launch vehicle standard services will be provided as GFE and the cost will not be included in the cost cap. The cost of mission specific and special launch services, including the use of radioisotope heating units (RHUs), is the responsibility of the PI, and must be included within the cost cap. NASA is reviewing the possibility of offering options for different launch vehicle capabilities and their impact on the cost cap.
- Investigations are capped at a Phase A-D cost of \$450M (FY15), excluding standard launch services. The now-standard 25 percent minimum reserve on Phases A-D will be required within the cost cap. Operations costs (Phase E) are *not* included in the cost cap, but will be evaluated for reasonableness. Lower-cost investigations and cost-efficient operations are encouraged.

The following observations can be offered as they relate to technology infusion and addressing accommodation costs of implementing new technology capabilities:

- NASA is accepting greater risk for the infusion of NEXT by being willing to provide it as GFE.
- Use of EP on missions can enable missions to utilize smaller and lower cost launch vehicles. Restricting launch vehicle options to larger more costly launch vehicles can de-incentivize the use of a new technology. The excess C₃ from a larger launch vehicle can negate the benefit from using EP and result in a lower PI cost, but a higher overall total cost once the launch vehicle cost is added in. By allowing lower cost launch vehicle options it would allow proposers to design missions using the advanced technologies to enable the mission requiring smaller launch vehicle

capabilities and resulting in a lower overall cost, and therefore, increasing the science value for the cost.

- The use of these advanced technologies can enable more challenging missions to outer solar system destinations. By judging Phase E operations costs on cost-efficient operation, missions to the outer solar system destinations using any of these advanced technologies won't be at a cost-competitive disadvantage compared to inner solar system missions that are likely to have shorter flight times and therefore lower Phase E operations costs.
- The TDO option allows for technology demonstration and validation without impacting the cost risk for the proposed mission. It would be judged and funded on its own merit, as long as its accommodation does not impact the cost or risk of the proposed mission.
- Requiring any re-entry mission to accommodate GFE sensors and instrumentation will allow for the gathering of needed atmospheric data that will support model development and validation, and feed forward to lower as lower risk for future re-entry or aerocapture missions.

Summary

A Request for Information Action was released by the Planetary Sciences Directorate to understand and assess the progress of its Technology Infusion investments. An evaluation team based at NASA Glenn Research Center managed this RFI and collected inputs from the science and mission communities. These inputs include, but are not limited to, barriers to technology infusion as related to infusion approaches, technology readiness, information and documentation products, communication, integration considerations, interaction with technology development areas, cost-capped mission areas, risk considerations, system level impacts and implementation, and mission pull. From the assessment of these inputs, a series of prioritized findings were compiled. Additionally, an extensive list of recommendations was developed between the RFI responses and the evaluation team's input.

For the first finding, it was widespread position that the end-user community, including both industry and proposers, want to use NASA developed technologies to support PSD missions. In particular, these technologies enable missions that are of interest to the science community. However, the second finding was that there is a prevalent perception that these technologies are not ready for infusion into the missions. To resolve the readiness issues, it was recommended in multiple instances to complete the development of the technologies, thoroughly document them, and qualify the technologies for flight. Third, a major drawback to using these technologies is that it is perceived by proposers that SOMA judges new technologies as being too risky to accept proposals that use the new technology.

In the last Discovery AO, PSD provided incentives to encourage proposers to use new technologies such as NEXT and ASRG. The fourth finding was that the end-user community considered the technology incentives to be insufficient to overcome the risks and cover implementation and launch accommodation costs. As a result, PSD is losing credibility when it comes to technology development and infusion.

In response to these issues, the following recommendations were developed to address this situation:

- Develop an incentives approach for infusion technologies that addresses the completion of system-level development work (from TRL 6 to flight infusion) and accommodation costs/impacts
- Implement a defined, transparent, and independent process for validating and documenting that infusion technologies have achieved TRL 6 (or more), nine months (or more) prior to AO release
- Establish an approach to sustain technology capability so that future PSD mission needs can be met

Although there were many more findings and recommendations compiled in the Appendixes of this document, the above actions would significantly improve the chances for successful infusion of these technologies and subsequently bear fruit for PSD's investments.

An interest in improving technology infusion is not new. Appendix H contains extracts from four NASA related references/papers that the study team felt was relevant to this study, and would contribute to any steps taken to address its findings and recommendations. Finally, while this RFI was undertaken as a separate and stand-alone activity, the Technology Infusion Study findings and recommendations are consistent with and augment the Planetary Science Technology Review Panel (PSTRP, circa 2010 to 2011) (Ref. 6) and TRL Uniformity study findings and recommendations (2013) (Ref. 7).

Appendix A.—Charter

A.1 Planetary Science Division Technology Infusion Study, November 16, 2012

Charter: The Planetary Science Division within the Science Mission Directorate at NASA HQ seeks to understand how to better realize a scientific return on spacecraft system technology investment by enabling the first use of these technologies through competed mission opportunities. To this end, the PSD is forming a team comprised from the Radioisotope Power Systems Program and the In Space Propulsion Technology Program staff to execute this study. This team will engage the science and mission communities and seek inputs from industry, universities, and other organizations. This team also may seek opinions and analysis from consultants and contractors as needed to achieve the objective of this study.

This team will report to the Program Executives for the Radioisotope Power System Program and the In Space Propulsion Technology Program, who will coordinate with Program Executives and Program Scientists for the Mars Exploration, Outer Planet Flagship, Discovery and New Frontiers Programs as stakeholders in the study objectives.

A.2 Study Team Plan

Objective: Primary objective is to provide PSD with recommendations on how to effectively infuse new spacecraft systems technologies into future competed missions enabling increased scientific discoveries, lower mission cost, or both. This objective can be achieved by answering the following questions:

- How can technology efforts be better developed, communicated, and offered to allow for implementation into a competitively selected mission?
 - How mature does a new technology need to be before being recognized as viable and ready for infusion by the end user? And, what are the barriers to the use of newly developed technologies in competed missions?
 - What were the benefits and limitations of the technology incentive methodology used in the New Frontiers 3 and Discovery 12 AO's?
 - How can the technology incentive methodology be improved?
 - How did the DSMCE study impact the evaluation of the ASRG technology in mission concept planning and the development of a proposal in response to the Discovery 12 AO?
- How does PSD reduce real and perceived new spacecraft system impact on mission risk? (See Figure 1)
- From the end user perspective, are there any other viable options for technology infusion which NASA could consider?

There are two secondary objectives:

1. Understand Discovery 12 lessons learned from proposers and evaluators regarding the integration of the ASRG into mission concepts.
2. ISP objective understand lessons learned from proposers and evaluators regarding the use of NEXT, Aerocapture, and AMBR for Discovery/New Frontiers class missions. What were some specific reasons that these incentivized technologies were not proposed in response to the recent Discovery/New Frontiers AO's?

Approach: The approach is comprised of the following steps:

1. **RFI Phase:** In order to maximize our contact with the members of the science and mission communities it is recommended that a NASA Headquarters Request for Information (RFI) be

released. This RFI will be drafted by the study team and approved by the stakeholders. The RFI will request from the science and mission communities input on specific questions, their assessment of barriers to technology infusion as related to infusion approach, technology readiness, information and documentation, communication, interaction with technology areas, costs capped mission areas, risks, system level impacts and implementation, and mission pull at a minimum. The RFI will also notify the community that NASA may ask for one-on-one visits either virtually or face-to-face. The response time will be set for 45 days. Separately, the study team will work with the Discovery and New Frontiers PSs to notify the Discovery 12 and New Frontier 3 AO participants that specific lessons learned will be collected through individual contact in Phase 3. These targeted interactions will focus on the lessons learned from the recently completed Discovery and/or New Frontiers AOs which were unsuccessful in implementing the offered and incentivized spacecraft technologies.

2. **Analysis Phase:** During this phase the study team will generate common themes across the input received and identify any unique responses. This data will be reviewed to determine the contact plan. The results of this phase will be shared with the stakeholders prior to any contact with the outside community. Consideration will be given to grouping and follow-up with responders by organization, proposal teams, principal investigators, and mission managers at a minimum.
3. **Discussion Phase:** During this phase individual contact will be made with each of the proposers. There will be specific follow-up questions but these discussions will be structured to have a dialogue and better understand the community and allow for further understanding of the written response. This phase will also allow for the secondary objectives to be met.
4. **Report/Recommendation Phase:** This phase will document all information received and will abstract the information into recommendations to PSD that will achieve successful implementation of offering and utilizing new spacecraft technology in future PSD missions. A final report and presentation will be delivered.
5. **Post Main Study Phase:** In this phase the study team will share the results of this study with the broad science and mission community. This will be executed by arranging with each of the assessment groups a time a meeting to present the study and results and obtain feedback. After each interaction the study team will provide a short white paper on the communities' reception and feedback to the technology infusion recommendations.

Timeline: December 2012 through April 2013 for Phase 1 through 4. Post Study Phase 5 is not included in the schedule at this time. See notional schedule.

Deliverables: Deliverables include the final report and presentation describing the findings and recommendations, factors considered, top risks and all information provided by the science and mission communities.

Team Membership: Dave Anderson (ISPT), Carl Sandifer (RPSP), Dan Vento (ISPT), and June Zakrajsek (RPSP)

Cost: The majority of the work will be supported using current guideline budget within RPSP and ISTP program funds. It is expected that additional funding on the level of \$60K (TBR) will be needed to support additional travel and WYE support. Travel funds will be better understood in November after responses are received from the RFI.

Appendix B.—Request for Information (RFI)

B.1 Planetary Science Division Technology Infusion Study—General Information

Solicitation Number:	NNH13ZDA008L
Posted Date:	TBD
Proposal Due Date:	April 19, 2013
Recovery and Reinvestment Act Action:	No
Classification Code:	A – Research and Development
Issued By:	Science Mission Directorate
NAICS Code:	541712
CFDA Number:	43.001 Science

B.2 Introduction

The Planetary Science Division (PSD) within the Science Mission Directorate (SMD) at the National Aeronautics and Space Administration (NASA) Headquarters seeks to understand how to better realize a scientific return on spacecraft system technology investments. This Request for Information (RFI) will provide PSD with recommendations on how to effectively infuse new spacecraft systems technologies that it develops into future competed missions, enabling increased scientific discoveries, lower mission cost, or both. We are collecting input on how to maximize the return on and benefits from current technology investments and thereby improve the prospects of the inclusion of these investments within future competed missions' opportunities. We are requesting from the science and mission communities input on specific questions, their assessment of barriers to technology infusion as related to infusion approach, technology readiness, information and documentation products, communication, integration considerations, interaction with technology development areas, costs capped mission areas, risk considerations, system level impacts and implementation, and mission pull. Other volunteered input not supporting one of these areas from responders will also be considered.

To this end, the PSD has formed a team comprised of Radioisotope Power Systems (RPS) Program and In-Space Propulsion Technology (ISPT) Program staff to execute this study. This team will engage the science and mission communities and seek inputs from industry, universities, and other organizations. This team also may seek opinions and analysis from consultants and contractors as needed to achieve the objective of this study.

The most recent PSD Announcements of Opportunities (AOs) have offered the availability of the following technologies to the proposers: The Advanced Stirling Radioisotope Generator (ASRG), aerocapture and aeroshell hardware technologies, the NASA Evolutionary Xenon Thruster (NEXT) ion propulsion system, and the Advanced Materials Bi-propellant Rocket (AMBR) engine. Specific input on the use of these technologies is also being requested.

Following the collection of the data from this RFI, with agreement from the responder, NASA may request one-on-one visits either virtually or face-to-face with the responders.

B.3 Technology Infusion Study Process

This study will consist of five phases briefly noted below:

Data collection Phase: NASA is utilizing the RFI vehicle to collect a broad range of input from members of the science and mission communities. This input is requested through the questions contained in the attached appendices:

Appendix A provides the General List of Questions to be addressed by respondents regarding technology infusion barriers. It is requested that all respondents address these questions.

Appendix B provides the list of questions for the In-Space Technology Program

Appendix C provides the list of questions for the Radioisotope Power Systems Program. Appendix B and C can be addressed as determined appropriate by the respondents.

Appendix D is for reference regarding current targeted technologies and both programs.

The Assessment team will be contacting respondents, as appropriate, for additional detailed discussions during the Discussion Phase. NASA also intends to directly contact and work with known proposers from the Discovery 12 AO.

Analysis Phase: During this phase, the study team will generate common themes across the input received and identify any unique responses. The results of this phase will be shared with the PSD stakeholders prior to any contact with the outside community. The contact plan, for follow-on discussions with responders where considered necessary or requested, will be formulated based on the outcome of the activities in this phase.

Discussion Phase: During this phase, individual contact will be made with select RFI responders. There will be specific follow-up questions, but these discussions will be structured to have a dialogue and better understand the community and allow for further understanding of the written response. This phase will also allow for the technology specific questions to be discussed in greater detail.

Recommendation Phase: This phase will document all information received and will abstract the information into recommendations to PSD management that will identify opportunities to improve technology development planning and technology infusion opportunities for future AOs.

Post Main Study Phase: In this phase, the study team will share the common themes and results of this study with the broad science and mission community. It is envisioned that this will occur at appropriate planetary assessment group meetings and conferences and will cover the study results and seek feedback.

B.4 RFI Response Details

RFI responses must include:

- Name of the primary point of contact for the response and business title
- Institution or organization affiliation
- Postal address, E-mail address, and phone number
- Identification of other key individuals who collaborated on the RFI response
- Indication if the responder is willing to be contacted upon NASA's determination of need for further discussion
- Indication if the responder requests to be contacted. NASA will make every effort to contact those that indicate the request to be contacted.
- Responses to questions listed in Appendix A at a minimum, and Appendices B and C, as desired.

Response Submission Requirements:

- The response time has been set for 30 days.
- Responses to this RFI must be submitted no later than 11:59 p.m. Eastern Time, on April 19, 2013. RFI submissions will be accepted as E-mail attachments only. All responses must be sent to carl.e.sandifer@nasa.gov, with "PSD Technology Infusion RFI Response from..." in the subject line.
- All files with confidential or proprietary information should be sent via any means of secure file transfer. If a secure file transfer system is not available, please contact Carl Sandifer for assistance.
- Responses should include references as appropriate.

- Use single-spaced, 12-point, Times New Roman font.
- Requested file formats are: Microsoft Word (.docx) or Portable Document Format (PDF).
- An E-mail confirmation of receipt from NASA will be sent within a 1-week period to the designated point of contact.

Additional Details:

- Although all comments received will be carefully reviewed and considered for inclusion in any possible later action, the initiators of this request make no commitment to include any particular recommendations.
- Please ***do not*** include any proposal specific information in the response to the RFI, unless the description of some mission parameters are necessary to provide the necessary context for a response.

Disclaimer: This RFI is used solely for information planning purposes and does not constitute a solicitation. In accordance with FAR 15.201(e), responses to this RFI are not offers and cannot be accepted by the Government to form a binding contract. The Government is under no obligation to issue a solicitation or to award any contract on the basis of this RFI. The specific information provided in responses to this RFI will not be made public in an effort to protect any propriety company information. The RFI evaluation team will use the submitted information to complete the assessment; the results of which will be reported out. Nonetheless, respondents should clearly and properly mark any propriety or restricted data contained within its submission so it can be identified and protected. Respondents are solely responsible for all expenses associated with responding to this RFI. Responses to this RFI will not be returned, and respondents will not be notified of the result of the review.

Point of Contact for Submission Inquiries:

Carl E. Sandifer, II
Radioisotope Power Systems Program
Carl.E.Sandifer@nasa.gov
216-433-8727

Point of Contacts for Technical Inquiries:

David Anderson
In-Space Propulsion Technology Program
David.J.Anderson@nasa.gov
216-433-8709

June F. Zakrajsek
Radioisotope Power Systems Program
June.F.Zakrajsek@nasa.gov
216-977-7470

B.5 RFI Appendix A: Technology Infusion Study Questions

As mentioned in the Introduction, the primary objective of the PSD Technology Infusion Study, and, therefore, this RFI, is to provide PSD with recommendations on how to effectively infuse new spacecraft systems technologies which it develops into future competed missions enabling increased scientific discoveries, lower mission cost, or both.

Please respond to the following questions regarding planetary science missions in general and/or the most recent New Frontiers and Discovery Announcements of Opportunity (AOs). If you are commenting on a specific AO, such as Discovery, please specify that in your response:

1. What do you perceive are the barriers to new technologies being integrated into mission concepts and proposals? What do you recommend to reduce those barriers?
2. What improvements can NASA implement that can facilitate improved communication regarding new technologies, their capabilities, and maturity that would benefit science exploration?
3. Was the type and amount of information provided regarding the technologies adequate for an AO proposal development? What do you suggest to improve the information flow?
4. What should be the minimum technology maturity level required before a new technology is recognized as viable and ready for infusion? How should the maturity level be assessed and by whom? What data is required to make this assessment and what can NASA provide to assist in the decision making process? Can you provide any examples of when the assessment of maturity stopped a proposal from being developed or submitted?
5. Can you discuss how your company's decision process to invest in developing an AO proposal including a new technology is affected by the technology readiness level? What is recommended to reduce the risk and barriers at this phase of the life cycle?
6. Please discuss the benefits and limitations of the different technology incentivization methods previously used in the New Frontiers 3 and Discovery 12 AO's? How can the technology incentivization methodology be improved?
7. How can NASA reduce real and perceived spacecraft system risks when using new technologies?
8. From the end user perspective, are there any other viable options for improving technology infusion that NASA could consider?
9. Is NASA working on the right portfolio of technologies to benefit science exploration? What is missing and what may not be needed?
10. How long before the AO release does the community need to understand the incentivization method and the technologies being offered?
11. Please provide any additional comments regarding reducing the barrier of technology infusion.

B.6 RFI Appendix B: In-Space Propulsion Technology Program Technology Infusion Study Questions

The primary goal of the ISTP is to provide propulsion technologies that enable or enhance science exploration. To that end, please answer the following questions for any of the following In-Space Propulsion Technologies of interest or relevance to your organization:

- A. NASA Evolutionary Xenon Thruster (NEXT)
- B. Advanced Materials Bi-propellant Rocket (AMBR)
- C. Aerocapture maneuver, and/or aeroshell hardware technologies (TPS and hot structures)
- D. Hall Effect Electric Propulsion
 1. Is your organization considering using the above technologies for future missions and/or uses? If so, for what types of missions and/or uses? Are there any technology gaps to be addressed unique to these types of missions? Would conducting a "competed mission capability enhancement" study on ISPT products similar to the Discovery Scout Mission Capability Enhancement (DSMCE) studies for use of the Advanced Stirling Radioisotope Generator (ASRG) help with the understanding and infusion of these technologies, and if so, how?
 2. In your opinion, what minimum level of technology readiness, or other factors, would be required for the above technologies to be adopted by an end user for future missions? In addition, specifically address, as appropriate:

- a. Does NEXT need to have a fully TRL6 validated PPU and DCIU before being considered for a mission?
 - b. What additional development and qualification activities are required to enable AMBR to be included into future design concepts and missions?
 - c. Do the aerocapture maneuver and related technologies require a flight demo in order to be viable to be incorporated into future concepts and designs?
3. What are the high-risk areas for the above technologies that require further mitigation?
 - a. Are the interfaces sufficiently defined and provided for your implementation needs?
 - b. What is an acceptable risk tolerance at the proposal stage of the life-cycle?
 - c. What data is required to provide risk closure?
4. Regarding technology incentive approaches for the above technologies:
 - a. What are the minimum additional technology development milestones that must be met before your organization would consider proposing the above technologies without a cost incentive? Please be as specific as possible for individual subsystems.
 - b. If the above technologies are not matured further beyond this year, would cost sharing of the remaining development be sufficient for adoption of the technology in future proposals? What level of cost sharing would allow inclusion into your proposal?
 - c. Aside from offering these technologies as GFE, how would the incentivization method influence your decision to utilize the technologies listed above?
 - d. If these technologies are offered as GFE, do you think there is sufficient maturity to include it in an AO response?
5. Are there other considerations/subsystem technologies/system implications (spacecraft bus or mission operations) that may have impacted your decision and/or risk posture regarding the infusion of these technologies? Any quantifiable feedback would be appreciated. For example:
 - a. NEXT: Operations cost, increased solar array cost, operational complexity, etc...
 - b. AMBR: Increased thermal interface concerns, decreased feed system pressure margin, operational complexity, etc...
 - c. Aerocapture: Increased packaging complexity, cruise science opportunities, lack of expertise, etc...
6. Please discuss the following alternative technology considerations.
 - a. Is Aerocapture enabling for mission(s) under consideration by your organization, or do you have an alternative/preferred orbit capture option? What is this method and why is it preferred? Are the potential benefits of Aerocapture sufficiently defined and advertised, for you to be able to assess its influence on your mission? Are the potential benefits of new aeroshell materials sufficiently defined and advertised for you to be able to assess their influence on your mission?
 - b. If you evaluated the AMBR engine, did you down select to an alternative due to cost, risk, performance, etc.? If there were other factors, please identify and describe those factors.
 - c. Would you recommend another higher priority electric propulsion capability investment for Discovery and New Frontiers class missions other than NEXT? Specifically, if a ~4 kW-class Hall electric propulsion system for planetary missions would be available for the next Discovery AO (\geq TRL 6 by PDR), would it be proposed for mission(s) under consideration? What science mission needs would this system capability address?
7. Please discuss the impact the four ISPT technologies could have on achieving NASA's science goals and objectives
 - a. How much mission pull is there for the technology and for what types of missions are they considered enabling or enhancing?
 - b. Does this change with the customer (i.e. NASA SMD, NASA non-SMD, DOD, Commercial)?

8. What can be repurposed from the existing ISPT program? For example, much of the thermal protection system (TPS) work from Aerocapture may be used for other entry vehicle purposes (EDL, EEV, or probes)?
9. Are ISPT's existing analytical tools (Low Thrust Trajectory Tools (LTTT), Multi-mission Systems Analysis for Planetary Entry (M-SAPE), Propulsion Sizing Tool, etc...), sufficient for end user needs?

Other Spacecraft Technology Questions

1. What spacecraft bus technologies would be of the most interest to the planetary science mission community?
2. Are there cost effective spacecraft bus technologies that can be adapted from commercial or DoD applications?
3. Do you have any suggestions of other customers for spacecraft bus technologies relevant to NASA planetary missions?

B.1 RFI Appendix C: Radioisotope Power Systems Program Technology Infusion Study Questions

1. What considerations contributed to your decision to use an ASRG in your proposal? Please include availability of ASRG information in your answer. Was the ASRG information in the Discovery Program Library available early enough for your development cycle and/or schedule?
2. How did the Discovery Scout Mission Capability Enhancement (DSMCE) studies impact the evaluation of the ASRG technology in mission concept planning and the development of a proposal in response to the Discovery 12 AO?
3. Please comment on the AO library as the repository of ASRG AO information: the information data structure used, data updates, the ease of finding information sought, and the consistency of information. Did the Discovery Program Library contain sufficient detail into the more salient aspects of the ASRG?
4. The Discovery Program Office, RPS Program Office, ASRG Project Office, Department of Energy, and Launch Approval Engineering were all involved in the proposal process. What interaction did you have with each of these groups? How useful were these interactions? Were the frequency, timing and interchange of information sufficient? What suggestions would you have to improve these interactions?
5. Did the Advance Stirling Radioisotope Generator Information Summary (July 7, 2010), Updated July 30, 2010; The ASRG User ICD (June 9, 2010), updated July 19, 2011; and CDRL 7, ASRG System Specification (July 19, 2011) provide sufficient detailed technical insight into the ASRG design for your team? Please discuss these documents usefulness, clarity, level of detail, comprehensiveness, consistency and any issues you identified. What suggestions would you have to improve these documents?
6. Please comment on the adequacy of the models and supporting documentation provided. What additional models or improvement to the supporting documentation would you have found helpful?
7. Please comment specifically on the considerations and challenges encountered due to the unique aspects of using a radioisotope-based system. Specifically consider NEPA and Nuclear Launch Safety as well as integration and operational aspects. Please discuss the process used to educate your team in these areas. Also discuss the sufficiency, clarity, and usefulness of the information provided and the process used to convey this information. What, if any, suggestions do you have to improve the interchange and information?
8. Would you enumerate items, issues, and opportunities for improvement that would have enhanced your interactions with the ASRG Program/Project Team? Please identify areas where we could have made your proposal better, or your proposal generation process more efficient.

9. Please provide any additional feedback, positive or negative, that will help NASA improve future AO solicitations and processes involving radioisotope systems.
10. What was your general, overall assessment of your interactions with the ASRG Program/Project Team? What did you learn from this experience and what do you suggest for the future?
11. Please comment on any perceived or actual impacts resulting from the ASRG being designed in parallel to the AO process. Does this approach provide demonstrative or substantial benefits, including risk reduction? How mature does the ASRG technology need to be before being recognized as viable and ready for infusion by the end user? What suggestions would you have to improve this situation?

B.2 RFI Appendix D: References and In-Space Propulsion Technology Program Technology Descriptions

B.2.1 References

ISPT Web Site

<http://spaceflightsystems.grc.nasa.gov/SSPO/ISPTProg/>

RPS Website

<http://rps.nasa.gov>

Discovery Program Library

<http://discovery.larc.nasa.gov/dpl.html>

New Frontiers Program Library

<http://newfrontiers.larc.nasa.gov/NFPL.html>

NEXT Phase 2 Closeout Documentation and NEXT TRL Assessment (can be provided upon request)

B.2.2 Technology Descriptions

NASA's Evolutionary Xenon Thruster (NEXT)

The NEXT Ion Propulsion System (IPS) is an advanced 7-kW electrostatic xenon ion-thruster propulsion system developed for deep-space applications. The NEXT system development consists of a thruster, power processing unit (PPU) propellant management system (PMS), gimbal, and a digital control interface unit (DCIU) simulator. The thruster operates over an input power range of 0.5 to 6.9 kW, produces a maximum specific impulse of 4190 s, a thrust range of 26 to 236 mN, and a maximum thruster efficiency of 71 percent. In an on-going long duration test, the thruster has demonstrated over >800 kg of xenon throughput, >45,000 hr, and >30 mN-s of total impulse. The PPU operates from 0.65 to 7.2 kW and an input voltage range of 80 to 160 V with a peak efficiency of 95 percent. The PMS provides the necessary xenon flows for operating the thruster. The gimbal provides the mechanical actuation authority needed to maintain thruster pointing through the spacecraft center of mass. The individual components have been tested in performance and appropriate environment and integrated into system-level demonstrations.

The incentive provided by SMD in the last Discovery AO was the following:

- Use of NEXT IPS components including the ion thruster, power processing unit, propellant management system, digital control interface unit and gimbal.
- The ion thruster and power-processing unit were critical components for the NEXT IPS. The NEXT thruster is manufactured by Aerojet, and the NEXT PPU is being developed by L-3 Communications.

- Alternate propellant management system (Aerojet), DCIUs, and gimbals were acceptable.

Advanced Materials Bipropellant Rocket (AMBR) Engine

The AMBR (Advanced Materials Bipropellant Rocket) is a chemical rocket that has developed and applied an improved material processing technique to the iridium/rhenium rocket chamber manufacturing. The result was a high performance (high specific impulse), higher thruster radiation, cooled rocket engine that fits the same physical envelope as the R-4D rocket engine and operates on NTO/N₂H₄ propellants. The rocket demonstrated a thrust of 140 lbf, a maximum specific impulse of 333 s, when operated with an inlet pressure of 250 psia and an oxidizer-to-fuel ratio of 1.1. The test campaign included baseline hot-fire testing, shock and vibration testing, post-environmental performance testing, and long-duration testing. The testing duration totaled more than 9100 s, including 89 restarts and a single burn duration of 2700 s.

The incentive provided by SMD in the last Discovery AO was the following:

- Use of the AMBR engine, which consists of injector, combustion chamber, and nozzle hardware. AMBR is manufactured by Aerojet.
- Given the intent of demonstrating the AMBR materials processing technique, the combustion chamber would need to be fabricated using the demonstrated iridium/rhenium EI-form fabrication process.
- Alternate injector designs and alternate fuel/oxidizer combination (MMH/NTO) were acceptable.

Aerocapture

Aerocapture is the use of aerodynamic forces to slow an approaching vehicle and put it into a closed orbit about a planet. In contrast to aerobraking, aerocapture occurs in a single atmospheric pass, so orbit establishment is immediate. By accomplishing over 95 percent of the orbit insertion delta-V with drag, aerocapture saves significant propellant mass, allowing the use of smaller, more inexpensive launch vehicles, faster trip times, or increased payloads. The heating and aerodynamic loads on the spacecraft require that a heatshield, like that used for entry, descent and landing (EDL), be used for protection. The heatshield must also provide the aerodynamic shape required for autonomously controlling the vehicle to a specified target altitude upon exit, after which the heatshield is ejected and adjustments can be made to achieve the final orbit.

The incentives provided by SMD in the last Discovery AO were the following:

- Use of the aerocapture maneuver (guidance algorithm); flight software exists and could be provided by Ball Aerospace
- High-temperature aeroshell structure and TPS from ATK-Composite Optics and Applied Research Associates, Inc.
- Carbon-Carbon rib-stiffened hot structure aeroshell from Lockheed Martin Space Systems

Appendix C.—Background

C.1 Technology Development and Needs for Planetary Science Missions

Missions carried out for the Planetary Science Division (PSD) of NASA's Science Mission Directorate (SMD) seek to answer important science questions about our Solar System. In 2006, the Solar System Exploration (SSE) Roadmap (Ref. 2) identified technology development needs for Solar System exploration. The Roadmap described technology investment priorities are guided by the requirements established in mission and system studies. And that NASA should strive to maximize the payoff from its technology investments, either by enabling individual missions or by enhancing classes of missions with creative solutions to the general limitations on power, communications, and mass. It was further noted, that the breadth of technology needs for Solar System exploration calls for an aggressive and efficient technology development strategy, including acquisition of applicable technologies developed elsewhere in NASA, as well as in the government and commercial sectors.

The Roadmap discussed that certain technologies are of such a mission-critical nature that spaceflight validation is considered a prudent step prior to their actual use. The Roadmap highlighted that this could be done in two ways: on dedicated technology demonstration missions within the New Millennium Program, or by using other Solar System exploration missions as a platform for their validation. The purpose of the New Millennium Program (NMP) missions was to provide opportunities to validate technologies of a broad system nature, such as solar electric propulsion (flight-proven on the Deep Space 1 mission) or aerocapture. NMP also provided opportunities to validate sets of individual component technologies. The Roadmap noted that other technologies could be appropriate for validation on actual science missions in a non-mission-critical role. A point was made that early flight validation can ensure that the benefits of new technologies can be made available to future missions in a prudent and cost-effective manner. In 2007, a decision was made to conclude NMP, and it is no longer an avenue for flight validation.

The Roadmap described transportation and power technologies as highest priority (new developments are required for all or most roadmap missions). According to the SSE Roadmap, the highest priority propulsion technologies are electric propulsion and aerocapture, and the highest priority power technologies are radioisotope power systems with higher conversion efficiencies. The SSE Roadmap specifically states that "Aerocapture technologies could enable two proposed Flagship missions, and solar electric propulsion could be strongly enhancing for most missions. These technologies provide rapid access, or increased mass, to the outer Solar System" (Ref. 2). RPS, electric propulsion and aerocapture are suited for enabling significant science return for the outer planetary destinations under investigation.

In March 2011, the Planetary Science Decadal Survey (Ref. 3) was released and made many references to PSD technologies that were initiated in the previous decade such as radioisotope power systems like the Advanced Stirling Radioisotope Generator (ASRG), aerocapture, NEXT, an advanced chemical rocket engine called AMBR, as well as advancements made in the areas of astrodynamics, mission trajectory and planning tools. The Decadal Survey validated the technology investments ISPT and RPS programs have been making over the last 10 years, and it provides guidance for future technology investments.

The Decadal Survey noted that any planetary spacecraft, regardless of its specific destination, must cope with the fundamental challenges of traveling long distances from the Earth and Sun, surviving and operating over the resulting long mission duration, and operating without real-time control from Earth and with limited data streams. To address these challenges, the Decadal Survey identified multi-mission technology needs. The Decadal Survey Committee supported NASA developing a multi-mission technology investment program that will "preserve its focus on fundamental system capabilities rather than solely on individual technology tasks." For example, the Decadal highlighted the NEXT system development as an example of this "integrated approach" of "advancement of solar electric propulsion systems to enable wide variety of new missions throughout the solar system." The Decadal Survey made a recommendation for "making similar equivalent systems investments" in advanced solar array

technology and aerocapture. The Decadal Survey also discussed the importance of developing those system technologies to TRL 6. The Decadal specifically mentioned that:

- Investing in these system capabilities will yield a quantum leap in our ability to explore the planets and especially the outer solar system and small bodies.
- Perhaps more importantly, the availability of these systems is imperative in order for NASA to meet its solar system exploration objectives within reasonable budgetary constraints.

One recommendation from the Decadal Survey Committee was for “a balanced mix of Discovery, New Frontiers, and Flagship missions, enabling both a steady stream of new discoveries and the capability to address larger challenges like sample return missions and outer planet exploration.” These broad mission needs would in turn require a balanced set of multi-mission technologies and integrated system capabilities. The Committee acknowledges that a “robust Discovery and New Frontiers Program would be substantially enhanced by such a commitment to multi-mission technologies.” The in-space propulsion and RPS power technologies are applicable, and potentially enabling, for future NASA Discovery, New Frontiers, and sample return missions currently under consideration, as well as having broad applicability to potential Flagship missions.

The Decadal Survey also recommended the following features for a technology program that would meet future mission needs:

- The future of planetary science depends on a well-conceived, robust, stable technology investment program.
- Early investment in key technologies reduces the cost risk of complex projects, allowing them to be initiated with reduced uncertainty regarding their eventual total costs
- Continued success depends upon strategic investments to enable the future missions that have the greatest potential for discovery
- The technology program should be targeted toward the planetary missions that NASA intends to fly, and should be competed wherever possible.
- This reconstituted technology element should aggregate related but presently uncoordinated NASA technology activities that support planetary exploration,
 - Tasks should be reprioritized and rebalanced to ensure that they contribute to the mission and science goals expressed in the Planetary Decadal report.
- To properly complement the flight mission program, the Planetary Science Division’s technology program should accept the responsibility (with the required funding) to continue the development of the most important technology items through TRL 6.

The Decadal Survey stated as future mission objectives evolve, meeting these future challenges would require continued advances in several technology categories, including the following:

- Reduced mass and power requirements for spacecraft and their subsystems;
- Improved communications yielding higher data rates;
- Increased spacecraft autonomy;
- More efficient power and propulsion for all phases of the missions;
- More robust spacecraft for survival in extreme environments;
- New and improved sensors, instruments, and sampling systems; and of course
- Mission and trajectory design and optimization.

The Decadal Survey encourages technology infusion to enable more challenging mission requirements in the future. While expanding its investments in generic multi-mission technologies, NASA should encourage the intelligent use of new technologies in its competed missions. NASA should also put

mechanisms in place to ensure that new capabilities are properly transferred to the scientific community for application to competed missions. To enable or significantly enhance PSD's future planetary science missions, the In-Space Propulsion Technology (ISPT) and the Radioisotope Power Systems (RPS) programs are developing critical propulsion, RPS power, entry vehicle, and other spacecraft and platform subsystem technologies.

C.2 Discovery and Scout Mission Capabilities Expansion (DSMCE) Studies

In 2007 the Planetary Science Division released a new opportunity that looked for innovative Discovery and Mars Scout mission concepts. The Discovery and Scout Mission Capabilities Expansion (DSMCE) call solicited mission concept proposals for low cost planetary missions that require a nuclear power source such as the Advanced Stirling Radioisotope Generator (ASRG) currently under development by NASA. The DSMCE program was intended to foster the formation of mission design teams, beginning the discussion of necessary engineering trades, and discovering the breadth of missions never before possible without the addition of the ASRG technology to the Discovery and/or Scout programs. Mission design assistance for mission concepts was offered by NASA during the six month studies. Full details and mission concept parameters were available in the solicitation. Curt Niebur wrote a white paper called "Opening up the Box: ASRG Missions in the Discovery Program" where he noted that the DMSCE studies presents NASA with more mature, higher quality mission concepts from which to choose. (<http://lcpm9.jhuapl.edu/abstracts/028.pdf>).

The 2007 DSMCE ROSES Solicitation (NNH07ZDA001N-DSMCE) can be found at <http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId={01B70287-331E-25C2-B95F-6C80E03A1AF3}&path=past>.

The following website covers the DSMCE selections:
http://www.lpi.usra.edu/opag/march_08_meeting/presentations/dudzinski.pdf

C.3 Mission Applicability of Propulsion, Power, and Entry Vehicle Technologies

The Decadal Survey also identified a set of Discovery, New Frontiers, and Flagship class missions, and identified the technology needs for many of them. The study team assessed the propulsion, power, and entry vehicle technology needs for these Decadal set of missions and displayed the applicability in Table C.1. The spacecraft bus technologies which PSD has been developing for the last 12 years are applicable to 36 of the 47 identified missions contained in the Decadal Survey. A large number of additional mission studies have been completed and many proposed or yet to be proposed mission concepts are being considered which utilize these PSD developed technologies. The study team has compiled a more complete listing of mission studies that have been performed from a search of open source references.

PSD strongly emphasizes developing technology products for NASA flight missions that will be ultimately manufactured by industry and made equally available to all potential users for missions and proposals. The focus is on the development of new enabling technologies that cannot be reasonably achieved within the cost or schedule constraints of mission development timelines. Since 2001 PSD has been developing in-space propulsion and RPS power technologies that will enable and/or benefit near and mid-term NASA robotic science missions by significantly reducing cost, mass, risk, and/or travel times, or increase mission capabilities to reach more distant or challenging destinations. The PSD developed technologies will help deliver spacecraft to PSD's future destinations of interest.

TABLE C.1.—INFUSION TECH APPLICABILITY TO DECADEAL SURVEY MISSIONS

	New Frontiers 7 missions		Flagship 2013-2022 5 missions		Deferred High Priority >2023 6 missions		Other Missions and Tech Studies Considered 14 missions		Discovery Decadal Candidates 13 missions		Other Flagship 2 missions		Technology Total All Missions		Panels				
	Applicable	Critical	Applicable	Critical	Applicable	Critical	Applicable	Critical	Applicable	Critical	Applicable	Critical	Applicable	Critical	Primitive Bodies	Inner Planets	Mars	Giant Planets/Satellites	R&T Development
Propulsion																			
SEP (NEXT, Hall, REP)	^a 4	2	1	0	2	0	9	4	^a 8	^b	0	^b	24	6	X			X	X
High Impulse Chem (AMBR)	4	3	3	0	2	0	3	2	3	^b	2	^b	17	5		X			X
Trajectory Tools (SEP)	3	1	3	0	3	2	9	4	6	^b	1	^b	25	7				X	X
Entry Vehicle Technologies																			
Aerocapture	1	1	1	1	3	2	2	2	0	^b	0	^b	7	6				X	X
TPS/Entry Probes/EEV's	2	1	1	1	3	1	3	1	^a 4	^b	1	^b	14	4	X			X	
Power																			
RPS (ASRG, MMRTG)	5	1	3	2	3	1	5	3	^c 3	^{b,c}	1	^b	20	7	X			X	X
Photovoltaics	3	2	2	1	1	0	3	1	6	^b	1	^b	16	4	X	X			X
Applicable	7		4		5		8		10		2		36						
Critical		7		3		4		8		^b		^b	22						
Missions Identified in Decadal	7		5		6		14		13		2		47						

^a NOTE: There were two New Frontiers proposals with NEXT, and three NEXT and two Aerocapture/TPS related proposals for Discovery 12.

^b NOTE: Due to the open competition of Discovery missions, Criticality for Discovery-class missions was not highlighted in the Decadal.

SEP and Trajectory Tools Critical to small body, high delta-V, and outer planet Missions, TPS/Entry Probes/EEV's Critical to probes, hostile enviro landers, and sample return missions, and RPS/ASRG Critical to outer Solar System and Venus surface missions. Applicability could be a measure of need/use.

^c NOTE: There were nine ASRG missions identified in the DSMCE AO. There were seven Discovery 12 proposals with ASRG and 2 were selected for Phase A studies.

The NASA uses a system for rating where in the development cycle any particular technology resides. This system, called the Technology Readiness Level (TRL), and the current TRL scale and descriptions can be found in NPR 7123.1B (Ref. 8). The ISPT and RPS programs aim to develop technologies in the mid TRL range (TRL 3 to 6+), and which have a reasonable chance of reaching maturity in 4 to 6 years, and reduce risk sufficiently for mission infusion.

C.4 Providing Incentives to Infuse NASA-Developed Technology

NASA recognizes that it would be desirable to fly new technologies in order to enable scientific investigations or to enhance an investigation's science return. Discovery and New Frontiers missions potentially provide opportunities to infuse advanced technologies developed by NASA and thereby advance NASA's technology base and enable a broader set of future missions. The 2006 Solar System Exploration Roadmap (available in the respective Discovery or New Frontiers Program Libraries) identifies technology development needs for solar system exploration and states that NASA will strive to maximize the payoff from its technology investments, either by enabling individual missions or by enhancing classes of missions with creative solutions. The Roadmap identifies transportation technologies as a "highest priority" and notes that solar electric propulsion could be "strongly enhancing" for most missions.

In order to maximize the payoff from its technology investments, NASA provided incentives to encourage the infusion of ASRG, the NEXT or the AMBR engines, or aerocapture technologies into mission proposals in response to the Discovery 12 AO in 2010 (Ref. 5), and provided incentives to encourage the use of NEXT and AMBR in the New Frontiers 3 AO in 2009 (Ref. 4). Proposers were offered the option of selecting one (or none) of these specific technologies for insertion into their missions.

C.5 2010 Discovery 12 Announcement of Opportunity

SMD's In-Space Propulsion Technology (ISPT) program has developed several technologies that are nearing TRL 6 and that are, therefore, potentially applicable to Discovery missions (Ref. 5). Three of these technologies are: 1) the NEXT ion propulsion system, 2) the Advanced Material Bi-propellant Rocket (AMBR), and 3) aerocapture. ISPT investments in electric propulsion technologies have included completing NEXT, a 0.6 to 7 kW throttleable gridded ion propulsion system. ISPT investments in chemical propulsion have included a high-temperature storable bi-propellant rocket engine providing higher performance for lower cost than current state-of-the-art high performance rocket engines. ISPT investments in aerocapture have completed the development of a family of efficient thermal protection system (TPS) materials and structures; models for aerothermal effects; engineering atmospheric models which include Titan, Neptune, Mars, and Venus; guidance, navigation, and control (GN&C) algorithms for blunt-body rigid aeroshells; and will complete GN&C hardware in the loop ground testing.

For the ISPT developed technologies, the incentives reflected NASA's willingness to share in the flight development costs of the proposed advanced technology, up to a maximum amount depending on which technology is proposed:

- For missions that utilize NEXT, the cap on the PI-Managed Mission Cost will be raised by \$19M (FY 2010);
- For missions that utilize AMBR, the cap on the PI-Managed Mission Cost will be raised by \$5M (FY 2010);
- For lander missions that propose to use aerocapture, the cap on the PI-Managed Mission Cost will be raised by \$10M (FY 2010).
- For orbiter missions that propose to use aerocapture, the cap will be raised by \$20M (FY2010).

To qualify for an infusion incentive, a proposed mission must meet minimum demonstration requirements for its chosen technology. Those requirements were contained in the document In-Space Propulsion Technologies Minimum Demonstration Requirements located in the Program Library. Proposers were responsible for the required NEXT, AMBR, or aerocapture flight hardware development and integration, including the flight hardware development schedule. In order to continue improving its product development approach and ensure its future products are ready to transition to flight development, the ISPT program asked to monitor the NEXT, AMBR, or aerocapture flight hardware development; receive IV&V test results; flight development lessons learned, and performance data during flight.

SMD's Radioisotope Power Systems (RPS) program, in collaboration with the Department of Energy (DOE), is developing the Advanced Stirling Radioisotope Generator (ASRG). DOE had contracted with Lockheed Martin Space Systems Company and Orbital Sciences Corporation for the development, fabrication, and testing of the ASRG. The specifications, qualification schedule, and interface control document describing the ASRG were provided in the Program Library. Proposers could have elected to use up to two ASRGs only if use of a radioisotope power system enables their investigation (both Baseline and Threshold Science Missions). Satisfying this enabling attribute meant that the science goals to be achieved by the proposed mission cannot be accomplished reasonably with a nonnuclear power system. NASA would have provided two fueled and fully qualified ASRGs (valued at \$54M FY 2010) as Government Furnished Equipment at no cost to the proposer. The units would have been available for integration at NASA's Kennedy Space Center no earlier than March 2014. Investigations could have chosen to use one ASRG as a flight unit and the other as a flight spare or to use both ASRGs as flight units. The ASRG qualification unit may not be used as a flight spare. The use of radioisotope power systems will entail considerations of range and nuclear launch safety requirements in spacecraft and mission design.

The Discovery 12 AO (Ref. 5) provided guidelines for infusion of NASA-developed technologies. NASA SMD assumes the responsibility for maturing these technologies to TRL-6. Therefore, proposals that include utilization of one of these NASA-developed technologies were not required to include a

maturation plan for them. Proposals will, however, be required to include a plan for the infusion of these technologies. However, as these are technology development projects, NASA was not able to guarantee the anticipated performance under conditions different than those for which they have been designed and tested. It was the responsibility of selected proposers to assess any risk inherent in application of these technologies beyond the design envelope. The application and scope of any proposed use of NASA-developed technology was evaluated for appropriateness and conformance to the guidelines presented in the AO. The implementation feasibility and risk of the proposed use of NASA-developed technology will be evaluated against the factors in this section. All proposers will receive feedback, if applicable, on their proposed use of NASA-developed technology. Any PI considering the use of either of these technologies, and requiring further information, was afforded the opportunity to contact the respective technology point of contact (POC) at NASA's Glenn Research Center.

C.6 2009 New Frontiers 3 Announcement of Opportunity

NEXT and AMBR were also incentivized in the 2009 New Frontiers AO. (Ref. 4) The technology incentivization process was very similar to what was in the Discovery 12 AO, (Ref. 5) but differed in the following manner. Proposers were offered the option of selecting one (or neither) of these two specific technologies for insertion into their missions. With the incentives, NASA would share in the flight development costs of the proposed advanced technology, up to a maximum amount depending on which technology is proposed. For missions that utilize NEXT, the cap on the PI-Managed Mission Cost will be raised by \$15M (FY 2009); for missions that utilize AMBR, the cap on the PI-Managed Mission Cost will be raised by \$5M (FY 2009).

Table C.2 provides a high-level ISPT assessment of potential NEXT and AMBR applicability to candidate New Frontiers missions.

TABLE C.2.—POTENTIAL NEXT AND AMBR APPLICABILITY TO NEW FRONTIERS MISSIONS

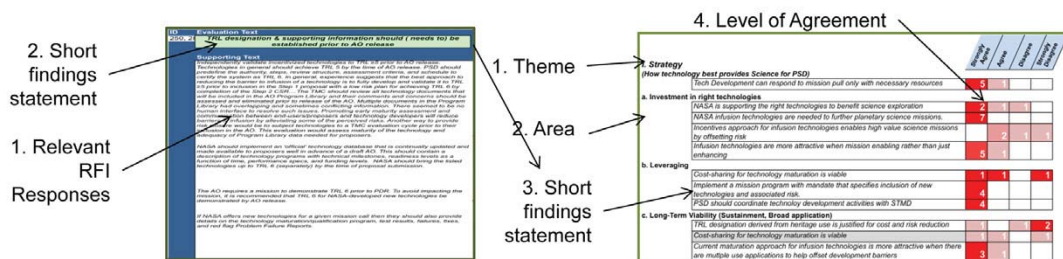
Candidate New Frontiers Missions	NEXT Applicability	AMBR Applicability
South Pole-Aitken Basin Sample Return	Limited applicability	Limited applicability
Venus <i>In Situ</i> Explorer	Limited applicability	Limited applicability
Comet Surface Sample Return	High degree of applicability	High degree of applicability for some mission designs
Network Science	Limited applicability	Likely not applicable
Trojan/ Centaur Reconnaissance	Limited applicability	Likely not applicable
Asteroid Sample Return	High degree of applicability	High degree of applicability for some mission designs
Io Observer	Applicable	Applicable
Ganymede Observer	Applicable	Applicable

Appendix D.—Findings

D.1 Findings Development Process

Process for Capturing and Consolidating Findings

1. Extracted **545** relevant responses from **190** pages into a database
2. Grouped similar extracted responses and developed **71** short finding statements
3. Consolidated statements into the **4** common themes from the Planetary Science Technology Panel's (PSTRP) Issues & Recommendations
 - Strategic, Process/Structure, Resource, and Culture/Communication
4. Determined level of respondent agreement within the finding statement



D.2 General Findings

The findings are organized into the themes developed by the PSTRP into Strategic, Process/Structure, Resource, and Culture/Communication. Each theme is divided into subcategories. The findings statements are listed under the corresponding categories identified by the team. The findings were originally organized generally by context but listed arbitrarily and given a numbers solely for identification. The identification number in green in the first column has a letter associated with the number is to identify the technology such as General Findings (F), NEXT (N), Hall (H), AMBR (M), Aerocapture (C), ASRG (A). The last column refers to the corresponding issue identified in the PSTRP Final Report which is found in Appendix F.

		Strongly Agree	Agree	Disagree	Strongly Disagree	PSTRP Issue Linkage
I. Strategic: Technology Investment Portfolio						
"How technology enables science for PSD"						
a. Investments in right technologies						
F2	NASA is supporting the right technologies to benefit science exploration	2	1	1		C1
F3	NASA infusion technologies are needed to further planetary science missions.	7				
F4	Infusion technologies are more attractive when mission enabling rather than just enhancing	5	1			
		Strongly Agree	Agree	Disagree	Strongly Disagree	PSTRP Issue Linkage
II. Process/Structure: Technology Development and Implementation						
"How to ensure technologists are infusion ready"						
a. TRL/MRL/SRL Development and Validation						
F15	TRL should be established at system level (not targeted components)	6				S2, P3
F16	TRL designation derived from heritage use is justified for cost and risk reduction			1	2	S2, P3
F17	Infusion technology should be demonstrated under representative conditions before offering	3	1			S2, P3
F18	TRL designation & supporting information needs to be established prior to AO release	8				S2, P3
F19	TRL designation should be determined by independent party (someone other than tech developer)	6				S2, P3
b. Long-Term Viability (Sustainment, Broad Application)						
F7	Current maturation approach for infusion technologies is more attractive when there are multiple use applications to help offset development barriers	3				S5, C1
		Strongly Agree	Agree	Disagree	Strongly Disagree	PSTRP Issue Linkage
II. Process/Structure: AO Implementation						
"How best to infuse technology into missions"						
a. Prioritize Technology Infusion						
F9	Implement a mission program with mandate that specifies inclusion of new technologies and associated risk.	4				C3
F20	Technology Infusion effort would benefit from DSMCE-like study	2	2		1	
F12	TCMO perceived as 'risk averse' and resistant/opposed to inclusion of new technology	6				C3
b. Incentives						
F10	Cost of maturation & implementation of infusion technologies is satisfied by current incentives			3	5	R1, R2
F11	Incentives approach for infusion technologies enables high value science missions by offsetting risk		2	1	1	C1, C3
F8	Provision of targeted technologies/system as GFE AND NASA holds risk is viable	1	1			C3
Criteria						
F13	Requirements for AO submission (input, assumptions, criteria, etc.) are fully communicated to proposing teams			2	3	P1, C2
F14	Increased transparency in proposal review process and criteria would clarify impact of risk on selection	3	3			P1

		Strongly Agree	Agree	Disagree	Strongly Disagree	PSTRP Issue Linkage
III. Resources						
"How can resource availability and utilization improve technology development and infusion"						
a. System Impacts/Barriers						
F21	Critical accommodation costs (implementation, launch vehicle & safety, integration) are not covered by current incentives	4				R2, C1
F1	Tech Development can respond to mission pull only with necessary resources	6				R1, R2, C1
b. Leveraging						
F5	Cost-sharing for technology maturation is viable	1		1	1	R2
F6	PSD should coordinate technology development activities with STMD	4				S3, S5, P4, R3

		Strongly Agree	Agree	Disagree	Strongly Disagree	PSTRP Issue Linkage
IV. Culture/Communication						
"How can culture and communications be improved to support technology development and infusion"						
a. Data Products						
F18	TRL designation & <u>supporting information</u> needs to be established prior to AO release	8				C2
F23	Infusion technology documentation is fully matured to meet the user needs for spacecraft integration	1		1	4	S2
F24	TCMO has sufficient information to properly evaluate technology risk to ensure 'level playing field'				3	C2
b. Teaming						
F25	Direct communication with SMEs is critical to resolve risk and help ensure successful mission development.	4				P4

D.3 Infusion Technologies: NEXT

		Strongly Agree	Agree	Disagree	Strongly Disagree
NEXT Ion Propulsion System					
TRL					
N1	NEXT system at TRL 6 & ready for spacecraft integration		2	1	3
N2	NEXT thruster is at TRL 6	4	1		
N3	NEXT PPU is ready for integration			1	6
Priorities					
N4	Maturation of NEXT system is recommended	5	1		
Technology Development & Availability					
N5	NEXT system is more attractive when there are multiple use applications	1	2	1	
N6	NEXT is at risk of heritage/technical expertise obsolescence	3	1		
Incentives					
N7	Current incentive approach is sufficient for NEXT system maturation and associated accommodation costs			3	2
N8	Provision of NEXT system as GFE is viable	2	3		
N9	Cost-sharing for NEXT maturation is viable	1	1	1	1
Studies					
N10	NEXT system application would benefit from DSMCE-like study	1	2		1
Accommodations					
N11	NEXT system requires increase/higher power system on spacecraft	3			

D.4 Infusion Technologies: Hall Effect Thruster

		Strongly Agree	Agree	Disagree	Strongly Disagree
Hall Effect Thruster for Planetary Science missions					
TRL					
H1	Hall Effect Thruster (HET) system is at TRL 6 & ready for spacecraft integration	1	2		
H2	Candidate HET is at TRL 6	1	1	1	
H3	HET PPU is ready for integration			1	2
Priorities					
H4	Maturation of a HET system is recommended	4	1		
H5	HiVHAc HET is ready for infusion into AO class missions			1	2
Technology Development & Availability					
H6	HET system is more attractive when there are multiple use applications	2			
Incentives					
H7	Provision of a HET system as GFE is viable	2			
H8	Cost-sharing for a HET system maturation is viable		2	1	1

D.5 Infusion Technologies: AMBR Thruster

		Strongly Agree	Agree	Disagree	Strongly Disagree
AMBR					
TRL					
M1	AMBR engine technology ready for spacecraft integration			1	4
M2	AMBR engine must be qualified to TRL ≥ 8 to warrant consideration	4	1		
Priorities					
M3	AMBR engine technology is of interest for future mission applications	1	2	1	2
Technology Development & Availability					
M4	AMBR system is more attractive when there are multiple use applications	1	1		
M5	Significant redesign of AMBR engine is required to foster interest and proposal support	3			
Incentives					
M6	Cost of maturation of AMBR covered by current incentive approach			2	2
M7	Provision of AMBR as GFE is viable	1		2	
M8	Cost-sharing to complete AMBR maturation is viable			1	1
Studies					
M9	AMBR adoption would be enhanced with a focused capability enhancement study (ala DSMCE)	1			1

D.6 Infusion Technologies: Aerocapture

		Strongly Agree	Agree	Disagree	Strongly Disagree
Aerocapture					
TRL					
C1	Aerocapture technology can be considered for future AO releases without flight demo		2	2	1
C2	Aerocapture technology is sufficiently understood/defined to enable spacecraft integration		1		1
Priorities					
C3	Aerocapture technology is of significant interest for future science mission applications	1	1	2	
Technology Development & Availability					
C4	Aerocapture technology application would be expanded through the use of new materials	1	2		
Incentives					
C5	Aerocapture technology infusion does not require direct cost incentivization		2		
C6	Cost-sharing for aerocapture infusion is viable		1		
Studies					
C7	Aerocapture technology adoption would benefit from a focused capability enhancement study (ala DSMCE)	1		1	1
Significant Comments					
C8	Aerocapture infusion limited by institutional/organizational constraints				

D.7 Infusion Technologies: ASRG Technology

		Strongly Agree	Agree	Disagree	Strongly Disagree
ASRG					
TRL					
A1	ASRG is at TRL 6 & ready for spacecraft integration				3
Incentives					
A2	Incentivized approach of providing ASRG hardware as GFE was necessary but did not address additional RPS system implementation costs borne by the mission	2			
A3	ASRG development in parallel with AO was effective			2	2
Studies					
A4	DSMCE studies for ASRG provided valuable opportunities to develop necessary technical insights for successful proposal development	3	1	1	
Communications					
A5	Direct communication between proposal team and technical experts was invaluable at early proposal stages & should be expanded	3	1		
Constraints					
A6	ASRG should be matured for use on flight mission through an efficient joint development effort with NASA providing effective leadership	4			
A7	ASRG infusion hindered by complex organizational relationships between supporting agencies	1	1		
Project & Program Library					
A8	ASRG Project provided required information, through the Program library, that was sufficient and valuable to proposal process				4
A9	Technical data of required quality, rigor, and scope was available in Program Library			1	3

Appendix E.—Recommendations

The Recommendation are from two sources, recommendations from the RFI Respondents listed under ID as “R#” and recommendations made by the Tech Infusion Study Team listed under ID as “T#” in Table E.1. The references under the “Support Findings” column are found in Appendix D of the Technology Infusion Study, and Appendixes F and G if preceded by “PI” or “PS”.

Key	
Direct	Direct linkage to a Tech Infusion, PSTRP, or TRL uniformity Finding/Observation/Issue
Indirect	Indirect relationship, supportive linkage, or Findings of insufficiency linked to a Finding that it needs to be completed
Tech Infusion	F-General A-ASRG C-Aerocapture N-Next H-Hall M-AMBR
PI ##	Planetary Science Technology Review Panel (PSTRP) Observation/Issue; Area #..., Appendix F
PS M#	Planetary Science Technology Review Panel (PSTRP) Major Recommendation: #..., Appendix G
TRL-U	PSD TRL Uniformity Study (Ref. 7)

TABLE E.1.—RECOMMENDATIONS

ID	Recommendation Wording	How Details	Supporting Findings	
R# - RFI Respondent, T# - Team-based			Direct	Indirect
II. Process/Structure - AO Strategies for Tech Infusion				
R2	(R2) PSD through the AOs should establish/designate missions that mandate the use of infusion technologies	* (R8) Determine the science missions that would benefit significantly from infusion technologies	F9, F12	F2
R1	(R1) Incentives approach for technologies considered for infusion must address the completion of system-level development work (from TRL 6 to flight infusion) and address accommodation costs/impacts	* (T9) Any technology being considered for incentivization must have an assessment of readiness and associated risk. *Qualify a new technology to DRM requirements, then re-qualify as necessary to Mission specific requirements when known * (T8) Evaluate accommodation of technologies considered for infusion to mitigate barriers in the AO incentive approach (cost, risk, knowledge, etc...). See (R7) for accommodation cost determination step.	F10, F21	F11, F26
T5	(T5) PSD should present the incentive approach for the use technologies considered for infusion approximately 9 to 12 months prior to AO release to establish common understanding for SOMA, industry and mission implementers, and technology developers	a. Documentation validating TRL 6 of any technology considered for infusion should be released 6 to 9 months prior to AO release b. Incentive approaches should address maturation of the technology from TRL 6 to flight implementation	F12, F13, F14	F11
T3	(T3) To achieve more Decadal Survey science goals, PSD should increase the risk and cost that it is willing to accept regarding the use of technologies considered for infusion in future mission AO's.	* PSD should determine its threshold regarding GFE versus cost sharing incentive limits for each infusion technology (including accommodation costs/impacts) * The user community wants PSD to provide technologies as GFE and cover accommodation costs/impacts thru ATLO and Ops	F3, F4, F5, F8 PI-C4	F2 N8, N9, H7, H8, M7, M8, C5, C6, A2
II. Process/Structure - Technology Development and Implementation				
<i>Technology Development and Systems Engineering</i>				
R7	(R7) Determine accommodation costs/burdens associated with new technology adoption factor into future missions	Account for accommodation costs/burdens in R2	F10, F21 N11	F12 N7

TABLE E.1.—RECOMMENDATIONS

TABLE E.1.—RECOMMENDATIONS				
ID	Recommendation Wording	How Details	Supporting Findings	
R# - RFI Respondent, T# - Team-based			Direct	Indirect
T4	(T4) Establish approach to sustain technology capability so that future PSD mission needs can be met	* Develop PSD unique requirements to meet mission needs, and identify if technology needs are PSD unique * Evaluate use or modification of commercial products to meet PSD unique mission requirements * Develop PSD unique technologies with industry (transferring the technology out of PSD) to open the possibility of commercial flight opportunities * Commercialization/"Multiple-use" should be considered at the beginning of technology development for risk reduction and establishing flight heritage	F7 N5, H6	
T2	(T2) The use of mission capability enhancement studies should be expanded to improve both the understanding of mission requirements and the constraints associated with implementing new technologies		F20 N10, A4	F7
Technology Readiness and TRL Evaluation				
R4	(R4) Implement a defined, transparent, and independent process for validating and documenting that a technology being considered for infusion has achieved TRL 6 (or more) 9-months (or more) prior to AO release	* (R5) A technology to be considered for infusion should be at a system-level TRL 6 nominally 6-18 months prior to AO release.* (R11) Improve and maintain documentation for technologies being considered for infusion to ensure necessary information is available to interested parties* Establish independent body to conduct TRL determination	F12, F14, F16, F18, F19, F23, F24 PS-M6, PS-M7, TRL-U all recs	A8, A9
T1	(T1) Complete development and qualification of the current infusion technologies (ASRG, NEXT, etc...) to alleviate risks and meet the needs of future PSD missions	* (T10) Finish technologies with a flight demonstration by any means to establish flight heritage -- (e.g., mandate the infusion technologies on an AO, funds for ride shares, re-establish New Millennium for NASA developed technologies, or negotiate TDM opportunities) * (T6) Qualify to a set Decadal Survey DRM's and/or generic requirements from mission user need derived by holding a User Community TIM and/or vet through a Technology Advisory Panel	F9, F12, F15, F17 N4, H4, M2, M3, C1, A6	F26 N1, N3, H1, H3, H5, M1, M5
IV. Culture/Communication				
R10	(R10) Improve and ensure robust communication opportunities between technology developer, mission manager, and proposing communities to encourage better understanding of technologies considered for infusion	* (R6) Ensure a representative POC or subject matter expert is available with authority to communicate and advise interested parties to ensure technologies considered for infusion are used properly to maximal benefit * (E13) NASA should ensure that all interested parties have fair and equitable access to the technologies considered for infusion * (T5/E5), (T2/E12), and (T6/E15) are also "how's" for this recommendation	F23, F24, F25 A5 PS-M8	A7 PS-M9
T6	(T6) Establish a customer advisory board to advise PSD on technology needs, performance requirements, and evaluation approaches to ensure level playing field for all parties	(T8) Institute evaluation processes to avoid placing barriers to infusion of new technologies in the AO process	F7 PS-M3, PS-M4 PS-M8	F2, F4

TABLE E.1.—RECOMMENDATIONS

TABLE E.1.—RECOMMENDATIONS				
ID	Recommendation Wording	How Details	Supporting Findings	
R# - RFI Respondent, T# - Team-based			Direct	Indirect
	R3	(R3) Develop partnerships with other organizations to broaden interest, appeal, and create sustaining support for technologies considered for infusion * (T11) Establish agreements to maximize cost sharing opportunities within the Agency (SMD, STMD, HEOMD) * (T12) Foster and maintain partnerships for advocacy between technology developers and users	F7, F6 PS-M5	A7
III. Resources				
	R9	(R9) Imperative that PSD complete technology development of the infusion technologies (ASRG, NEXT, etc...) to guarantee adoption into missions * Provide sufficient and sustained resources to mature new/infusion technologies to TRL 6 by AO release* To ensure satisfactory development of infusion technologies, shorter development timescales will improve infusion with mission opportunities* Establish dedicated PSD spacecraft component technology program to assist future infusion activities, and provide sufficient resources to sustain PSD unique technical expertise/knowledge and facilities in NASA, industry, and academia	F1, N4, H4, A1, PS-M10, PI-R1, PI-R2	N1, N3, H1, H3, H5, M6, A3
I. Strategic				
	T7	(T7) Provide resources to enable successful technology infusion and being a "smart buyer" for PSD unique/critical mission needs * Establish dedicated PSD spacecraft component technology program to assist future infusion activities, and provide sufficient resources to sustain PSD unique technical expertise/knowledge and facilities in NASA, industry, and academia	F2, F3, N2, C4 PS-M11, PS-M2 PI-R1, PI-R2, PI-C5	N6

Appendix F.—PSTR Major Technology Development Observations/Issues

Inputs to the PSTR team were collected and placed into four categories. The four categories include strategic, process/structure, resources, and culture/communication. Table F.1 lists the issues by category. The issues are listed in priority order by category. The priorities were generated by the panel considering the opinions and discussions that occurred within the larger PSTR team. No attempt was made to prioritize one category above another (Ref. 6).

TABLE F.1—PSTR MAJOR TECHNOLOGY DEVELOPMENT OBSERVATIONS/ISSUES

Issue Number	Technology Development Observation/Issue
Strategy	
S-1	No overall strategy or accountable manager
S-2	No clear path for technology maturation from TRL 0-9
S-3	Limited engagement of other NASA OCT, ESMD, and ESD technologists
S-4	Technology should be perceived as more than just hardware development
S-5	Efforts by external stakeholders are not worked into PSD strategy
Process/Structure	
P-1	Programs are not consistent and do not have clearly defined processes
P-2	Technology managers are overloaded and often oversee flight projects
P-3	Inconsistent and inaccurate TRL and heritage assessments
P-4	Limited processes that encourage interaction between stakeholders
Resources	
R-1	Technology budgets are unpredictable
R-2	Technology budgets are insufficient
R-3	Inadequate leveraging of other's investments
Culture/Communication	
C-1	Technology investments have not yielded all the benefits they could have
C-2	Inadequate communication (in and out)
C-3	Projects are too risk averse to new technology
C-4	Tenuous commitment by top management
C-5	Need to better sustain capabilities

Appendix G.—PSTR Major Recommendations

Suggestions for the resolution of the issues were collected by the PSTR team and the inputs from the PSTR team were used by the civil servant members of the panel to generate draft recommendations. The draft recommendations were sent back out to the full PSTR team and the science, technology, and mission communities for additional feedback. The civil servants then generated the final recommendations (Table G.1). The result of the process is a set of 11 major recommendations grouped into the same categories as the issues, with an added category for management (Ref. 6).

TABLE G.1.—PSTR MAJOR RECOMMENDATIONS

Major Recommendation
Management
MR-1) Establish a dedicated Director position with overall responsibility for PSD technology
MR-2) Establish a small supporting program office
Strategy
MR-3) Develop a comprehensive strategy for PSD technology
MR-4) Strategically allocate resources (guidelines are provided by PSTR)
MR-5) Actively pursue a strategy of leveraging opportunities within and outside NASA
Process
MR-6) Develop a more consistent and accurate TRL assessment process
MR-7) Develop clear, transparent, and consistent decision and review processes
MR-8) Develop a more structured and rigorous process to create interactions between technologists, scientists and missions
Culture and Communication
MR-9) Develop an overall communication plan and technology database
MR-10) Foster a culture that advocates for and defends technology
Resources
MR-11) Dedicate stable funding at the higher end of the decadal suggested range - 8 percent

Appendix H.—Summary of Four NASA Technology Infusion Studies/Papers

An interest in improving technology infusion is not new. Below are extracts from four NASA related references/papers that the study team felt were relevant to this study. The four references are listed below:

Reference 1, “Technology Infusion for Space-Flight Programs” by Andrew Shapiro, 2004

Reference 9, “Technology Infusion Planning within the Exploration Technology Development Program” by David C. Beals, 2007

Reference 10, “A Fast Technology Infusion Model for Aerospace Organizations” by Andrew A. Shapiro, Harald Schone, David E. Brinza, 2007

Reference 11, “Technology Transition a Model for Infusion and Commercialization” by Vernotto C. McMillan, 2006

H.1 Definition of Tech Infusion

Andrew Shapiro, of JPL, in a 2004 paper defined technology infusion as the pathway by which technologies, previously unused by space flight programs, move from their current status onto space flight missions. The technology can be several generations old, the state-of-the-art or anything that is deemed useful to the accomplishment of NASA space missions. Shapiro also noted that there is a development “gap” between laboratory bench research and development (R&D) and flight-ready systems (Ref. 1).

H.2 Technology Infusion Challenges

Shapiro described that programs are generally inclined to fund technology infusion tasks when they have little choice and it can be clearly demonstrated that the new technology under investigation is one of very few viable paths to mission success. He noted that under the current approach that Programs have no direct incentive to test technologies that are not on their most conservative paths. The objective of most Programs is to reduce risk to their program and curb their costs, and that the adaptation of new technologies is perceived to increase risk and increase costs. There may be some indirect incentives for including technologies with possible benefit to the program; however, without a strong motivation, the programs have no reason to consider anything new. Shapiro noted that technologies have worked in past programs tend to be favored because the project designers are familiar with them and are not taking any risks by using them (Ref. 1).

David Beals, of LaRC, described the Exploration Technology development Program (ETDP) in his 2007 paper as being comprised of a portfolio of advanced technology development projects. And that, a key aspect of the ETDP is the integration of the technology projects with mission design, architecture definition, flight system requirements and risks, and insuring the direct traceability of the technology products to flight applications. The ETDP projects are provided funding to the Technology Readiness Level (TRL) 6 level, i.e. the system has been tested on the ground and demonstrated performance functionality. However, Beals noted that the funding is insufficient to carry the investments made in the technology development phase through engineering and flight qualification, and that this situation has been endemic in prior technology programs; interesting and useful technology is funded without a defined plan to carry the projects through the development necessary to be incorporated into a flight project (Ref. 9).

Beals described that the key criteria for new technology insertion is cost/benefit, i.e., will the cost/schedule impacts of a new technology be commensurate with the benefit over the baseline approach? The benefits can be made clear by the linkage to performance and functionality requirement enhancements, but what is usually left out is assessing the technology from a systems Life Cycle Cost (LCC) point of view. This requires that the system and flight element have a configuration controlled LCC estimate (Ref. 9).

Beals articulated that criteria need to be defined for technology acceptance, and that the criteria are likely to include (Ref. 9):

- Benefit to the flight element: what performance/functionality/operational advantages does the new technology have over the baseline system and are these advantages significant enough to warrant inclusion?
- Cost of infusion: what is the cost to the project for changing from the baseline system to the new technology?
- System LCC: does the new technology reduce the LCC and is this reduction significant enough to warrant inclusion? This potentially involves assessments of operations and maintenance over the life of the vehicle/project – these cost assessments are notoriously difficult to verify.
- Risk to the system: does inclusion of the new technology reduce or increase system risk or system safety? Vital to this assessment is the development of a risk assessment that can be seamlessly incorporated with the flight elements.
- Schedule: is the flight element’s production schedule helped or impeded by the inclusion of the new technology?
- Readiness: Does the new technology project meet the PDR exit criteria?

Beals noted that a systematic approach and the coordination of both the technology and flight program offices will be required in order to assure that technology development projects are used by future flight programs. By introducing the “flight-like” rigor into the technology project management and meeting the informational needs according the flight project’s schedule, there is a greater likelihood that the technology products will be incorporated and will be able to demonstrate contribution to the mission’s goals and objectives (Ref. 9)

Andrew Shapiro, Harald Schone, and David Brinza’s 2007 paper articulated that one of the difficulties encountered for spaceflight qualification methods is that there are no standard space environments. Missions to Mars are substantially different from earth orbiting or lunar missions. Additionally, Mars orbiting missions are significantly different from Mars roving missions. Although the environments are substantially different, a number of factors are very similar. Typically, launch vibration and shock loads are similar. Often general reliability requirements are also related. In an attempt to focus on the similarities between missions, they described a concept developed by Cornford and Gibbel of a two sigma environment or one in which captures about 95 percent of the space qualification requirements (two standard deviations above and below an “average” environment). This two sigma strategy would allow a particular technology to be evaluated by the majority of common spaceflight test methods removing the bulk of the risk for any individual mission. The individual missions would then only need to perform a small number of tests that pertain to that mission’s specific environment (Ref. 10).

Shapiro, et al, noted that most hardware is developed because it either improves the state of the art or it provides the satellite operator with a new capability. However since the performance is the primary motivator for the technology development effort, little to no investments are made in optimizing or assessing the manufacturability and reliability aspects of the new product. Addressing the reliability and manufacturability at the end of the hardware development process carries the risk factors that, for example, the design approach or the materials used are ill suited for the space environment, expensive to implement, or incompatible with the spacecraft operational requirements not related to parametric performance of the new technology. Obviously, any significant change at the end of the development cycle to accommodate technology infusion is expensive and results in significant delays. Instead, designing the technology with reliability and manufacturability in mind can significantly improve the chance of technology insertion at a reasonable cost and schedule. For this reason, we have chosen TRL 4 as the latest starting point for the infusion process. We have as a goal to identify the root cause, or physics, of the failure to provide the technology developer with the insight to mitigate the potential failure mode (Ref. 10).

H.3 Steps/Activities/Processes/Models to Improve Technology Infusion

Shapiro's 2004 paper discussed an infusion process where a particular technology should have several baseline requirements fulfilled to be seriously considered for infusion into flight programs. The following requirements need to be met before consideration, or funding to meet these requirements needs to be identified (Ref. 10).

- A clearly identified advantage the technology offers
- Significant reliability data
- Some production history (commercial or military)
- More than one qualified vendor
- Any additional testing for the particular space environment
- Multiple targeted NASA programs that will clearly benefit

Vern McMillan, of MSFC, in his 2006 paper described a model that would advance the TRL to an acceptable level for Program and Industry to afford large investments toward either commercializing or infusion into the program. The model identified the following four elements necessary for successful adoption (Ref. 11):

- a. Mission Directorate (MD) Technology Need (this element is the most important element because if there is no technology solution required, there is no need to pursue the development.
- b. Local Program Manager (Level 2) Buy In or Concurrence. This element is equally important because it is the program which is funded by the Mission Directorate to execute the overall effort. This manager must provide written support as well as put resources into the effort. This assures value added and increases the probability of acceptance of the technology if development is successful.
- c. External Partner involvement via leverages resources, innovative ideas, and capabilities. This entity will be key to the commercialization aspects of the effort.
- d. Agency IPPO / Technology Transfer Organization involvement. This element is essential to the facilitation, strategy development, commercialization planning, and seed funding aspects of the effort.

McMillan discussed a new technology infusion strategy that would involve three paradigm shifts, which should now viewed as part of a 360 degree cycle that would provide a continuous return on investment (Ref. 11).

- First would be to now recognize the MD Program as the primary customer.
- Second, would be to begin with the end in mind.
- And third would be no longer viewing infusion and commercialization as two opposite ends of the spectrum.

McMillan described a review of several projects and the associated factors revealed that they all contained the following same four elements (Ref. 11):

- A primary NASA mission directorate program technical need. This was an imperative to the project success. The MD program needed solutions to their technology gaps in order for the program to succeed.
- A commercial partner that collaborated in the development and put forth a major investment of their own resources for the purpose of being the commercial supplier of the technology. This was a commitment by the commercial partner and was needed for the successful completion of the

project. It also ensured that NASA would have a commercial provider should the technology prove successful.

- A local NASA program manager with enough interest in the project and outcome that they invested program resources into the collaboration and followed the developments through fruition. This afforded the MD program to truly pay attention to the developments and learn real time if those developments would impact the critical path of the mission.
- And finally, a technology transfer organization providing seed fund investment, commercialization planning strategy, and project facilitation throughout the project life. This was clearly essential to bringing the collaborative elements together.

Beals described ETDP's Technology Infusion Plan as providing a framework by which the technology projects will work with the flight element customer to develop a defined plan to incorporate the technology product into a flight element. The framework will not be prescriptive since each project is unique. In the case where a flight element has defined requirements and identified risks, the infusion strategy should be straightforward. In many cases, however, the targeted flight element is still under study and cannot provide clearly defined requirements or risks; these cases will require more of a process for developing an infusion plan. In all cases, a mature infusion plan will have common agreements and understanding that will allow both the technology provider and flight element customer to know the performance, cost, schedule, and risks of incorporating the technology products into the flight element (Ref. 9).

Beals discussed that technology infusion needs to be viewed as part of a system design and engineering process, and that the elements of this process include (Ref. 9):

- Design Reference Mission (DRM) and Design Reference Architectures (DRM and DRA)
- Capability requirements and needs
- Flight element performance requirements
- Flight element schedule
- System and Flight element Life Cycle Cost (LCC)
- Flight element risks
- Capability requirements to technology project definition and assessment
- Technology project development
- Technology project to engineering development transition
- Engineering development
- Flight qualification testing
- Technology insertion final assessment, including flight element entry acceptance criteria

Beals said that the recommended technology infusion process starts with Design Reference Missions (DRMs) and Design Reference Architectures (DRAs). It logically flows from these to capability assessments and investment recommendations, illustrated as follows:

- DRMs/DRAs
- Identification of capability needs and requirements
- Capability assessment that includes the known technologies which make up the capability
- Integrated analysis of the capability assessments which results in an investment portfolio, investment recommendations, and integrated development roadmaps
- Iterative feedback of these recommendations to the DRM/DRA designer

Beals discussed how this hierarchy establishes capability and technology traceability to mission needs, the ability of each capability and supporting technology to meet requirements, and serves as a reference source for testing design assumptions (Ref. 9).

Shapiro, Schone, and Brinza described the JPL “Technology Infusion Maturity Assessment” (TIMA) process. They noted that this process would be used to clarify the definition of the mission requirements, identify and address early difficulties resulting from mission architecture decisions, and gauge capabilities of competing technologies. JPL’s TIMA Process evolved from the Fast Technology Infusion initiative that exploited previously developed JPL process to assist in technology infusion, and are now using the process to help speed up the infusion process (Ref. 10).

Shapiro, et al, described the TIMA process as being constructed to address several of the recurring obstacles to successful technology infusion, specifically:

1. Customer (mission) requirements for using the technology were either miscommunicated, misunderstood, or under-defined,
2. The technology was deemed non-flightworthy in its current state of development (i.e., the technology was subsequently rejected because of some unforeseen engineering issues), and
3. Other nearly equivalent commercially-available technologies could possibly replace NASA-developed technologies.

The net result of these obstacles was that disappointingly few of the promising technologies emerging from the research laboratory stage as proof-of-concepts mature to actual use (Ref. 10).

The TIMA process takes the form of a series of facilitated group sessions in which participants provide information pertinent to the infusion of the specific technology being considered. Custom-developed software supports the TIMA process, enabling on-the-fly capture of information, supporting the combination of the gathered information, providing reasoning over that combination, and offering visualizations to help convey status of the information and its combination to the participants. Shapiro, et al, summarized the TIMA process as follows (Ref. 10):

Identify the customer requirements that the technology needs to meet before designers and managers will have adequate confidence to infuse the technology into a flight project. Assess the relative importance of those requirements by ascribing numerical weights to them in proportion to their estimated importance.

Determine the potential, relevant failure modes of the technology. Assess how the impact of each failure mode can affect the requirements by ascribing a numerical proportion of requirement lost were that failure mode to occur.

Identify all the options available to prevent, diminish, or detect and correct (before actual use) failure modes. TIMA refers to the range of such options as PACTs, shorthand for Preventative measures, Analysis, process Controls, and Tests (PACTs). Assess the effectiveness of each PACT against each failure mode, by ascribing a numerical proportion of the reduction in the failure mode’s likelihood or impact (depending on the type of PACT) application of the PACT will realize. Also, estimate the costs (dollars, schedule, etc.) of each PACT as part of an engineering model fabrication and test program for the technology in question.

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